A strategy to improve image quality of low-dose synchrotron radiation CT imaging for tissue engineering applications

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I. Introduction

Hydrogel scaffolds made from biomaterials are used to facilitate cell growth and tissue regeneration, and are essential in tissue engineering applications. Hydrogel scaffolds have very low density and synchrotron radiation X-ray computed tomography (SR-CT) shows high contrast for hydrogel scaffolds characterization [1]. However, the radiation dose is of a potential risk using SR-CT for high-resolution imaging *in vivo* [2]. Reducing the radiation dose has been challenging since low-dose results suffer from noise and artifacts, thus significantly degrading image qualities.

Improving the image quality for low-dose CT imaging has drawn considerable attentions over the past decades. Deep learning (DL) methods can help to denoise and remove artifacts; however, most DL based methods are trained in the supervised mode. Their success critically depends on a large number of paired high-quality data, which typically results in relatively high dose. Such high-quality data are sometimes limited or even impossible to be obtained in the biomedical *in vivo* studies.

We present a low-dose imaging strategy that combines paired high-flux sparse-view CT scan (HF-SV) and low-flux full-view CT scan (LF-FV) based on convolutional neural networks (CNN), namely Sparse2Noise. The task is to determine the parameters φ in network f_φ,

$$\hat{\varphi} = \arg min_\varphi \left\| f_\varphi(\mathbf{x}_S) - \tilde{\mathbf{x}}_F \right\|_2^2 \qquad (1)$$

where $\mathbf{x}_S$ and $\tilde{\mathbf{x}}_F$ are the HF-SV and LF-FV reconstructions, respectively. Sparse2Noise fills the sparse-view artifacts but doesn't learn the low-dose noise on target.

II. Experiments and results

We first evaluated Sparse2Noise on the data that were captured from the 3% w/v alginate hydrogel tissue scaffolds *in vitro* by means of the propagation-based imaging CT (PBI-CT) technique, one of SR-CT techniques. The PBI-CT imaging were performed at the BMIT 05ID-2 beamline, Canadian Light Source, Canada, at sample-to-detector distance of 1.5 m (30 keV and pixel size of 13 μm). For LDFV imaging, 1500 projections were collected with photon flux rate of 26.7 mGy/s (i.e., entrance dose rate) by using a 12-cm neutral density filter (NDF) and the corresponding exposure time was 20 ms/projection. This resulted in a dose of 0.8 Gy. For HDSV imaging, 75 projections were collected with the dose date of 971 mGy/s with no NDF placed and the corresponding exposure time was also 20 ms/projection. This resulted in a dose of 1.4 Gy.

Results in Fig. 1 show the noise and ring artifacts are clearly present on LF-FV and HF-SV images; and scaffolds are hard to be identified. By introducing Sparse2Noise, the noise and artifacts can be significantly reduced, thus enhancing the image quality. To produce the similar quality without Sparse2Noise, the dose would be increased to 28.32 Gy.

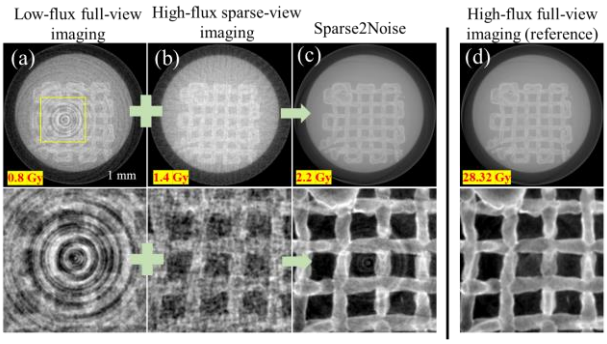

Fig. 1 Low-dose SR-CT data of hydrogel scaffolds; (a-c) processed results without and with Sparse2Noise, and (d) the high-dose results as reference.

III. Discussion and conclusion

The most important contributions of Sparse2Noise are summarized. First, compared to supervised DL algorithms, the proposed Sparse2Noise does not require high-quality reconstruction as reference during training. Both high-flux sparse-view scan and low-flux full-view scan involve relatively low radiation dose. This makes Sparse2Noise particularly useful in applications where high-dose scans are not

allowed. Second, Sparse2Noise based on CNN is more robust and computationally inexpensive compared to unsupervised deep learning algorithms. Third, Sparse2Noise can effectively obtain results with less noise and reduced ring artifacts at the same time. It is significantly important for low-dose SR-CT imaging in real applications.

Generally, an entrance radiation dose more than 6 Gy is generally considered lethal for small rodents [3]. According to typical *in vivo* micro-CT protocols with isotropic voxel size of ~50 μm, the tolerable radiation dose in live rodents imaging should be less than 0.5 Gy per scan [4]. We realized 2.2 Gy imaging for the isotropic voxel size of ~13 μm. If we double the isotropic voxel size to ~26 μm, the dose would be 0.14 Gy by using Sparse2Noise. Therefore, the method can be directly used for rodent imaging using SR-CT, at least for the isotropic voxel size of ~26 μm.

This study paves a way to *in vivo* visualization of hydrogel scaffolds using SR-CT with low radiation dose.

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References

[1] L. Ning *et al.*, "Noninvasive Three-Dimensional In Situ and In Vivo Characterization of Bioprinted Hydrogel Scaffolds Using the X-ray Propagation-Based Imaging Technique," *ACS Appl. Mater. Interfaces*, vol. 13, no. 22, pp. 25611-25623, 2021.

[2] K. D. Harrison *et al.*, "Direct Assessment of Rabbit Cortical Bone Basic Multicellular Unit Longitudinal Erosion Rate: A 4D Synchrotron-Based Approach," *J. Bone Miner. Res.*, vol. 37, no. 11, pp. 2244-2258, 2022.

[3] E.L. Ritman, "Micro-computed tomography—current status and developments, " *Annu. Rev. Biomed. Eng.*, vol. 6, pp. 185-208, 2004.

[4] N. Miyahara *et al.*, "Evaluation of X-ray doses and their corresponding biological effects on experimental animals in cone-beam micro-CT scans (R-mCT2), " *Radiol Phys Technol.*, vol. 9, pp. 60-68, 2016