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Improved visualization of breast micro calcifications in high spatial resolution quantitative susceptibility mapping using deep learning-based denoising.

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Abstract text

Introduction:

Cluster of microcalcifications (MCs) in the breast are considered a frequent precursor of malignant breast lesions[1]. In clinical routine, MCs are only detected by X-ray mammography. However, for young patients a radiation-free method would be strongly desirable. Quantitative susceptibility mapping (QSM) has been proposed for the MR-based visualization of calcifications based on complex multi-echo gradient-echo (mGRE) images. However, for the visualization of MCs, high spatial resolution is needed which substantially reduces the SNR. Deep learning-based denoising could be an approach to improve the apparent SNR for range of applications, including phase-sensitive ones like QSM[2,3]. Complex multi-echo images are well-known to contain Gaussian noise. The present work proposes the use of a bias-free denoising convolutional neural network (BFCNN) to denoise the complex mGRE images trained with artificial Gaussian noise[4]. Based on a simulation, the improved visualization of MCs when using denoising is demonstrated along with a proof of principle in an in vivo scan.

Methods

In vivo measurements

A high resolution effective multipeak in-phase gradient echo sequence was performed on a 3T scanner (Ingenia, Philips Healthcare)[5]. The imaging parameters were TE=[3.07,7.48]ms, FA=12, readout-direction=anterior-posterior, FOV=384×384×192mm^3, TR=10.85ms, compressed sense acceleration R=6, and an isotropic voxel-size of 0.6mm^3. The images were reconstructed online using the vendor"s compressed SENSE.

Pipeline

BFCNN, trained on Gaussian noise in grayscale images can robustly denoise across various Gaussian noise levels[4]. BFCNN was applied to the real and imaginary part of complex-MR data separately for denoising. A hierarchical multi-resolution graph-cut was used to obtain an unwrapped field map[6]. A nonlinear preconditioned total field inversion algorithm was used to invert the field map to susceptibility (χ) map7. Fig.1 shows the pipeline of denoising and QSM processing.

Simulation

Cluster of MCs with negative χ(<-1ppm) of one voxel size each(0.6mm^3) are simulated in a reference scan based on the in vivo scan. Gaussian noise was added to the reference scan (real & imaginary) and QSM was performed on noisy and denoised data.

Results

Fig.2 shows the magnitude data and estimated parameters for simulated the reference, noisy, denoised. The noisy χ-map(green) shows MCs like artefacts (dark voxels) while the denoised χ-map(red) only shows the

simulated MCs. Fig.3 shows the magnitude data and estimated parameters of original and denoised data. The effective noise removed can be seen in the difference maps especially further from the receiver coils.

Discussion

The BFCNN can substantially reduce the noise in real and imaginary part of the complex MR data. In the simulation, the noisy χ-map shows artefacts that could be misinterpreted as MCs. The denoised χ-map shows only true MCs that appear as single voxel of strong negative χ. Denoising improves visualization of MCs. Although no MCs are present in the in vivo scan, a substantial improvement in apparent SNR was observed, demonstrating the proof of concept for this approach.

Conclusion:

For high resolution QSM, low SNR limits the visualization of MCs. BFCNN substantially reduces noise in the complex MR data and s improves the apparent SNR in high resolution QSM to further enable the better visualization of MCs.

References:

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6:Boehm,Improved body quantitative susceptibility mapping by using a variable-layer single-min-cut graph-cut for field-mapping,MRM,2021

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Figure captions

Figure 1: Pipeline of QSM processing combined with denoising network. The HR scan is first denoised in the real and imaginary part using BFCNN and then denoised data is used to estimate field map using a hierarchical multi resolution graph cut method[6]. The field map from the denoised data is then inverted to χ-map using non-linear total field inversion[7].

Figure 2: Magnitude data and estimated parameters of simulated reference, noisy and denoised data are shown. It can be seen that in the noisy χ-map (reference-blue, noisy-green, denoised-red), MC-like artefacts appear. The denoised χ-map only shows the simulated MCs.

Figure 3: The first column shows magnitude, field map and χ-map of the in vivo scan of a volunteer. The second column shows its denoised versions. In the difference map (last column) the noise removed from the original data can be seen.

Fig. 1

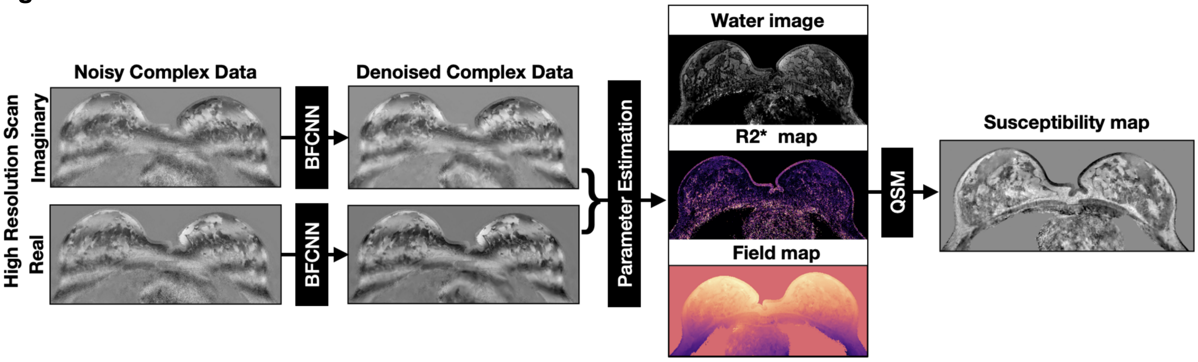


Fig. 2

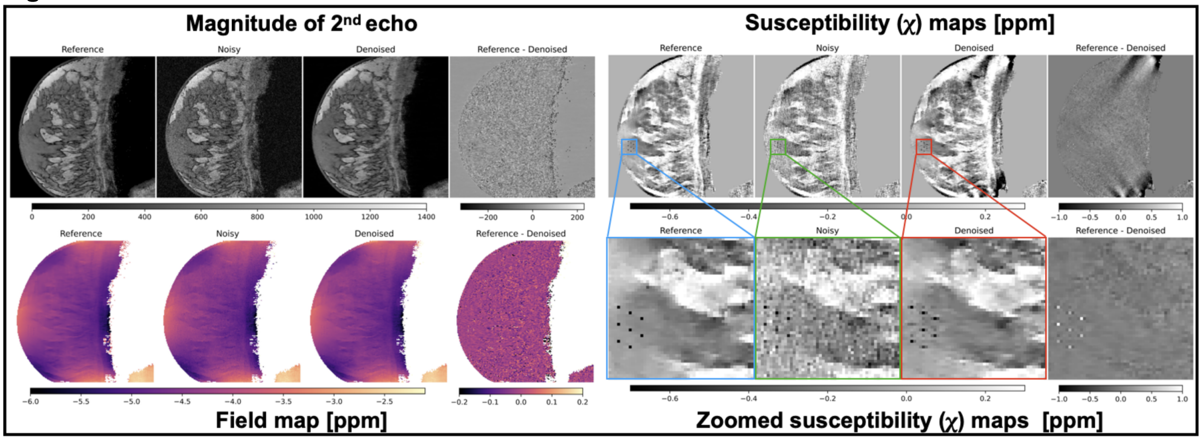
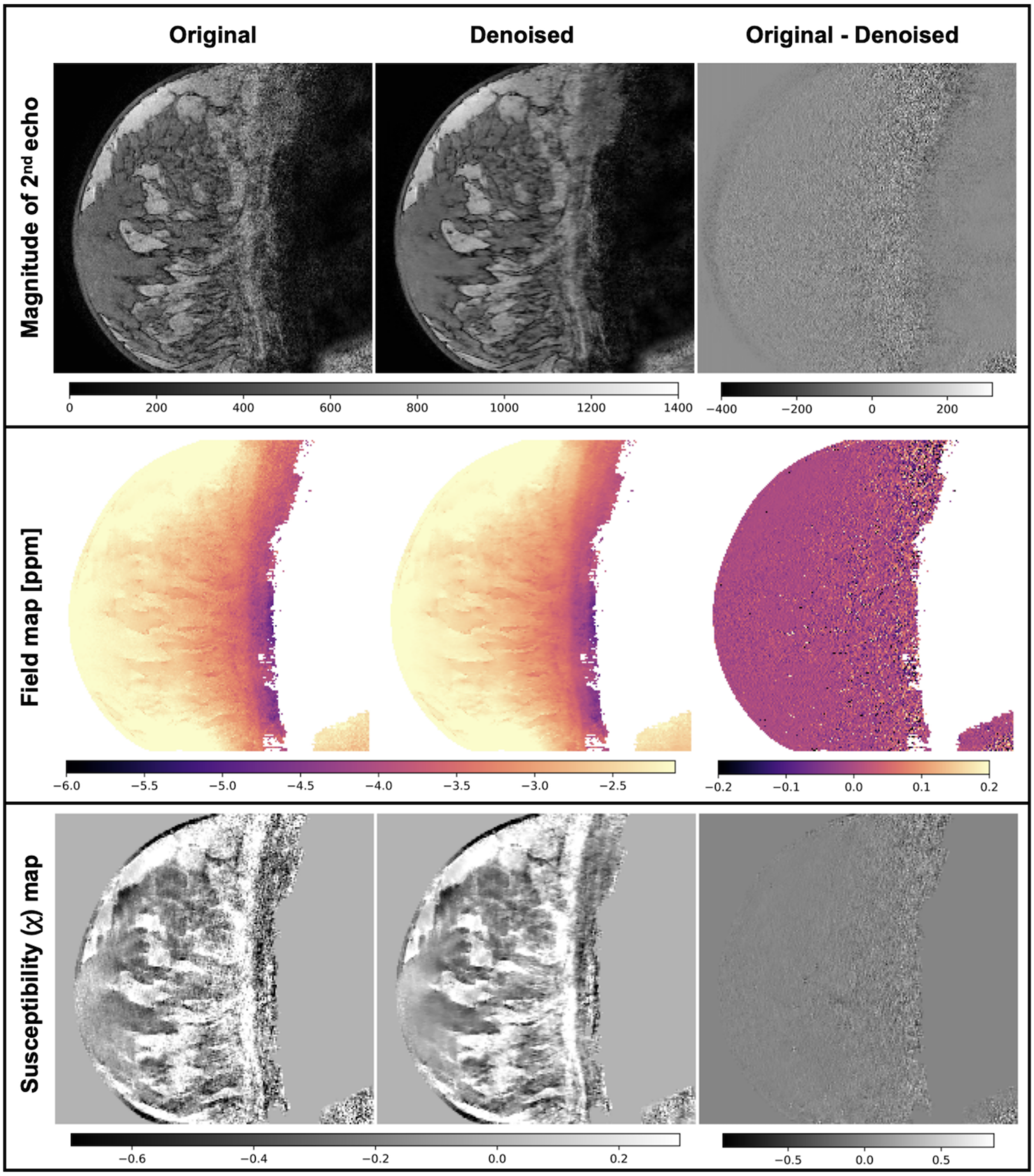


Fig. 3


Original
Denoised
Original - Denoised
Magnitude of 2nd echo
0
200
400
600
800
1000
1200
1400
−400
−200
0
200
Field map [ppm]
−6.0
−5.5
−5.0
−4.5
−4.0
−3.5
−3.0
−2.5
−0.2
−0.1
0.0
0.1
0.2
Susceptibility (χ) map
−0.6
−0.4
−0.2
0.0
0.2
−0.5
0.0
0.5