NEW REGULARIZATION TECHNIQUE FOR MRI SENSE RECONSTRUCTION IN STUDIES OF CORONARY ANGIOGRAPHY

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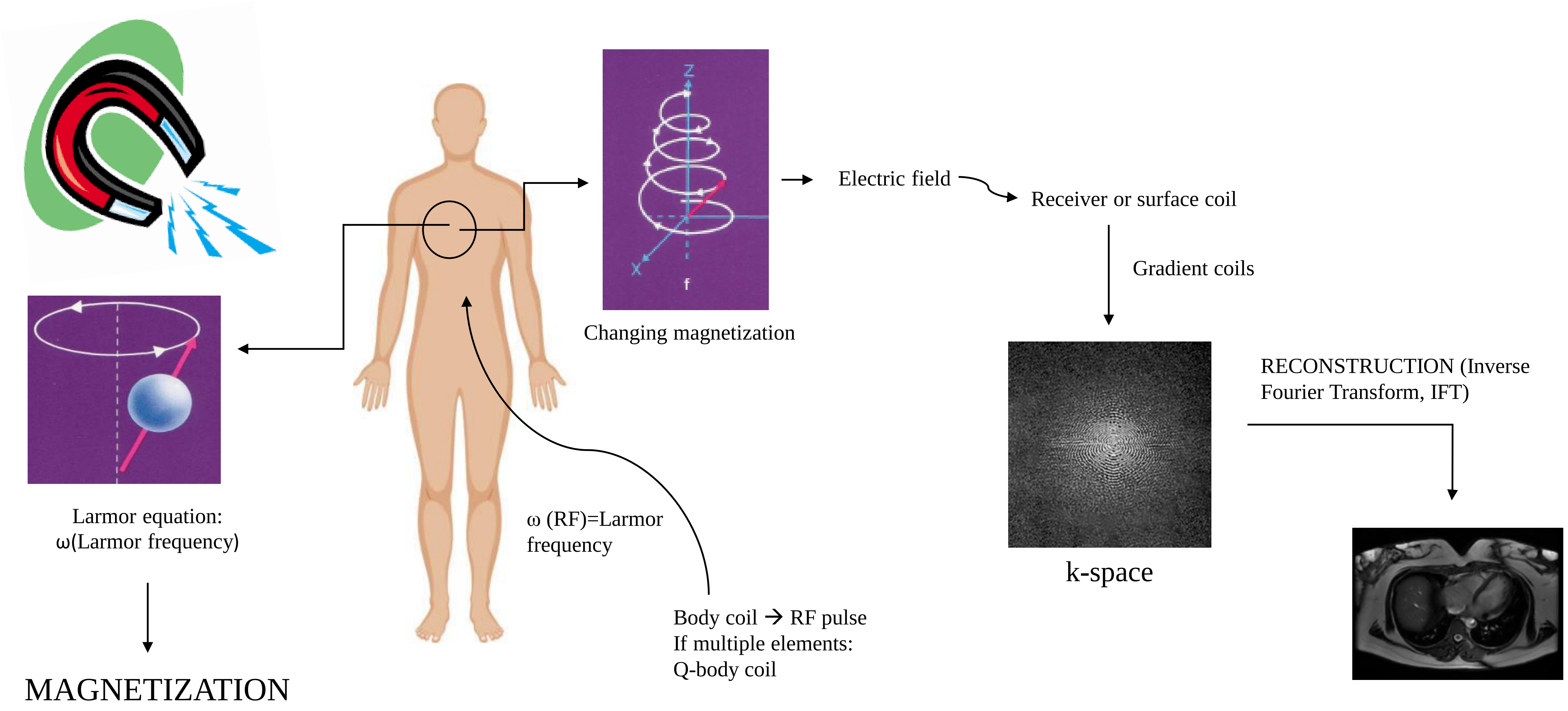
INTRODUCTION
MOTIVATION
&
OBJECTIVES

MAGNETIC RESONANCE IMAGING (MRI)



MR CORONARY ANGIOGRAPHY (CORONARY MRA)

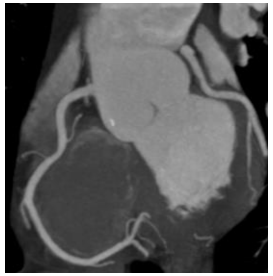
- Bright and intense blood (“bright blood”) → high signal
- Dark and weak myocardium and skeletal muscle → low signal

High contrast

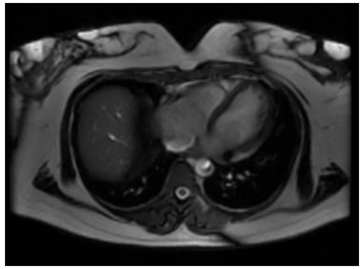
Standard set by Computer Tomography Angiography (CTA). However:

- No ionizing radiation
- No contrast media
- Non-invasive
- BUT… Too much time (About 3 min in MRA vs few seconds in CTA)

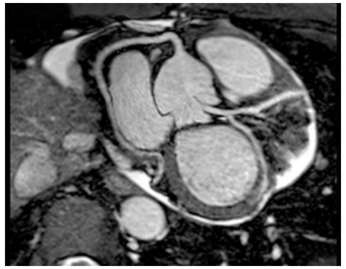
→ Acquisition time has to be reduced



Coronary CTA



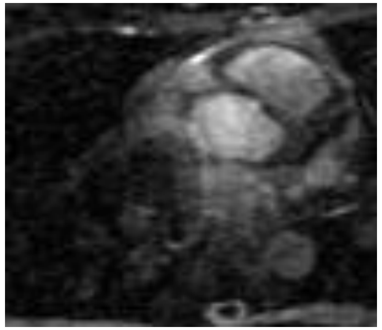
Conventional chest MRI



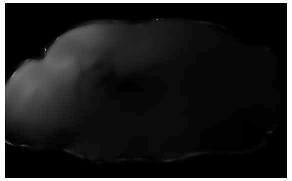
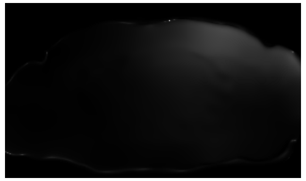
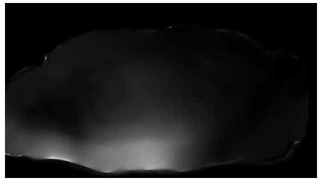
Coronary MRA

SENSITIVITY ENCODING (SENSE) RECONSTRUCTION

Reduce samples to acquire: $SENSE\ factor = \frac{Total\ samples}{Acquired\ samples}$ ⟶ Reduce time BUT aliasing (folding)



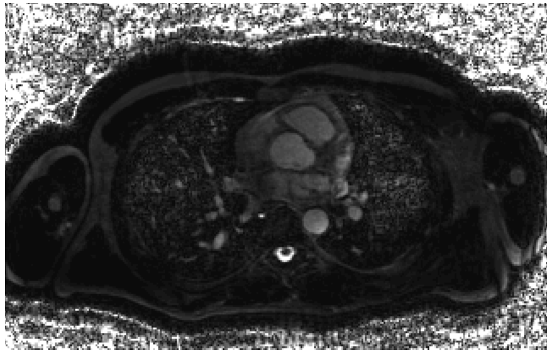
z: folded voxels

Several receiver coils at the same time → Parallel imaging → Sensitivity maps (Normalization with the Q-body coil) → Sensitivity matrices: S

⟶

UNFOLDING PROCESS



a: unfolded voxels

z=S·a → Compute the pseudoinverse with the conjugate transpose

$\mathbf{a} = \mathbf{U} \cdot \mathbf{z}$ (**Unfolding equation**) **Where** $\mathbf{U} = (\boldsymbol{S}^{\boldsymbol{H}} \cdot \boldsymbol{S})^{-\mathbf{1}} \cdot \boldsymbol{S}^{\boldsymbol{H}}$ **(Unfolding matrix)**

Noise amplification
- As SENSE factor increases
- Receiver coils' geometry may be defective

⟶ REGULARIZATION

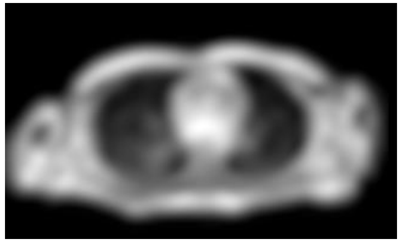
REGULARIZATION

1) Tikhonov regularization: $\boldsymbol{U = (S^H \cdot S + \lambda I)^{-1} \cdot S^H}$
   - Too low λ → INEFFECTIVE
   - Too high λ → too far from SENSE → folding artifacts

2) Singular Value Decomposition (SVD): $\boldsymbol{S = X \cdot diag(Singular\ values) \cdot Y^H}$
   - High Singular Values → high contribution of voxels to unfold
   - Low Singular Values → Noise → TRUNCATION by a certain factor (normally 10^{-5}) → Remove noise

Combined with Tikhonov, the final expression is: $\boldsymbol{U = Y \cdot diag\left(\frac{Singular\ values}{Singular\ values^2 + \lambda \cdot Largest\ singular\ value^2}\right) \cdot X^H}$

3) Introduction of prior information from the Q-body coil.
→ Multiplication to sensitivity maps and SENSE-reconstructed volume



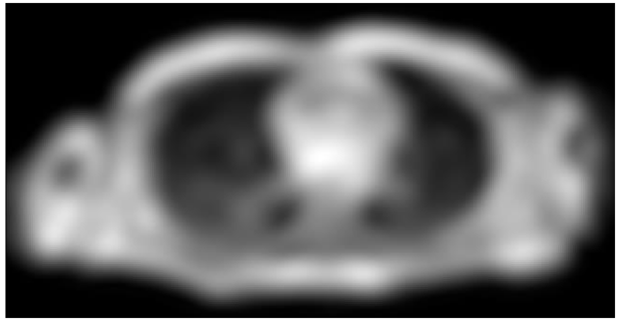
OBJECTIVE: STUDY ALTERNATIVE PRIOR INFORMATION TO FURTHER INCREASE SNR IN SENSE-RECONSTRUCTED IMAGES

OBJECTIVE ACHIEVEMENT

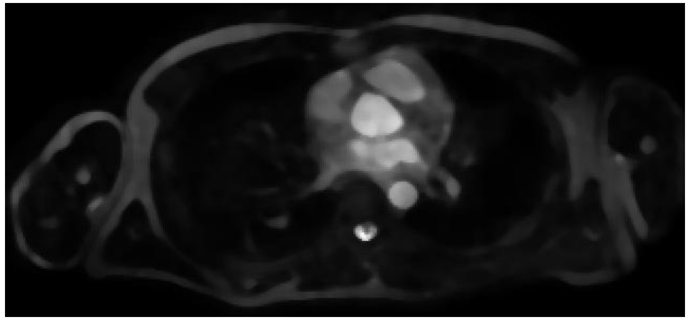
→ Implementation of a new regularization technique that takes as alternative prior an initial low-pass (LP) filtered SENSE reconstruction for a second and definitive SENSE reconstruction → try to enhance image quality.

- Initial reconstruction → use a combination of Tikhonov + SVD (λ_1) together with prior information from the Q-body coil.
- Second and definitive reconstruction → use a combination of Tikhonov + SVD (λ_2) together with the LP filtered initial reconstruction as prior.

→ Results comparison with state of-the-art methods in terms of SNR and CNR.



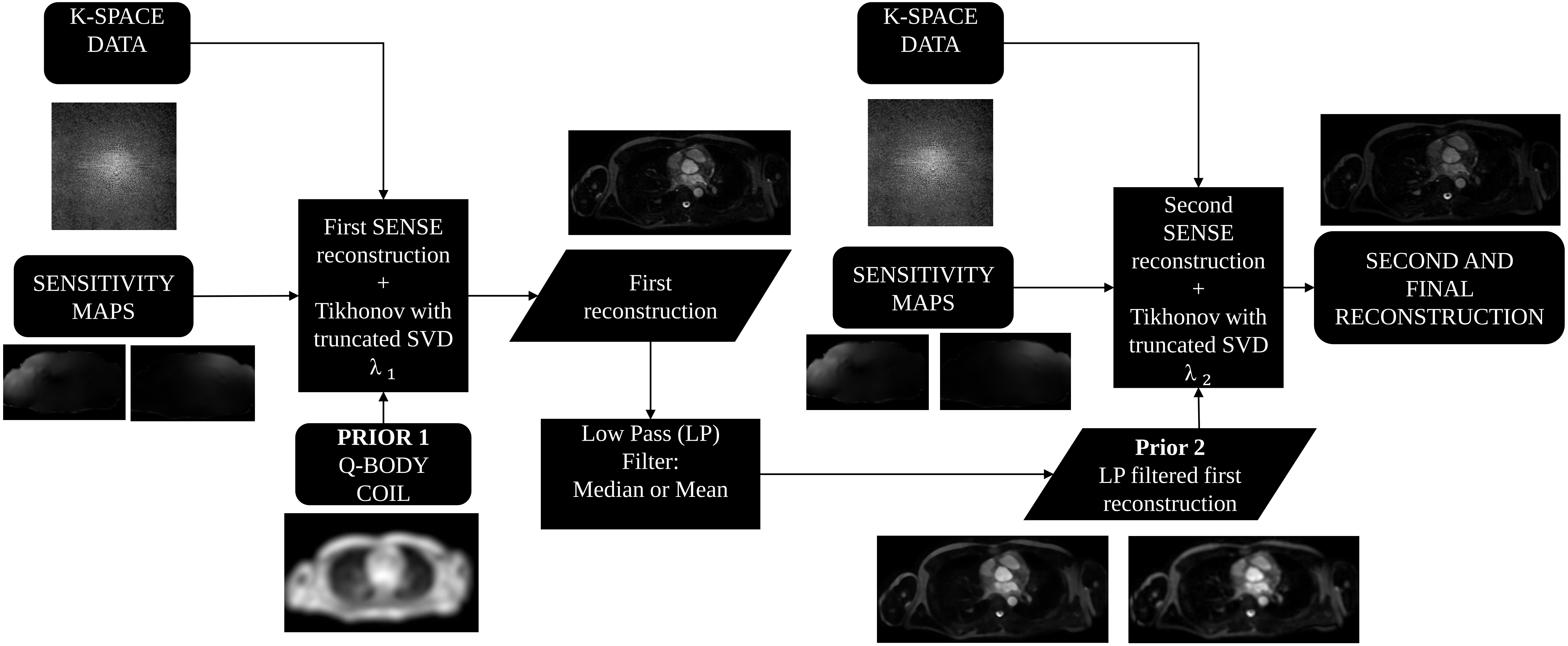
Q-body coil image → Prior for current methods. All tissues bright



Pre-reconstructed low-pass filtered image →Alternative prior. All tissues attenuated except for blood.

MATERIALS & METHODS

PROPOSED ALGORITHM



Median filtered Mean filtered

DATA ACQUISITION

- Coronary MRA → performed in a healthy volunteer in a 3T MR Philips scan at CNIC.

- The "bright-blood" MR sequence was acquired in 3D and isotropically → 1.5x1.5x1.5 mm^3 voxels in a Field of View (FOV) of 350x500x300 mm^3 in the thorax.

- Fat was suppressed → further increase contrast.

- Movement compensation → minimize the impact of movement artifacts.

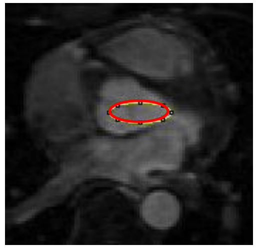
- Header and data files were produced → imported and read in IDL
  - K-space data
  - Surface coil data
  - Q-body coil data
    - Surface coils' sensitivity maps

ALGORITHM EVALUATION

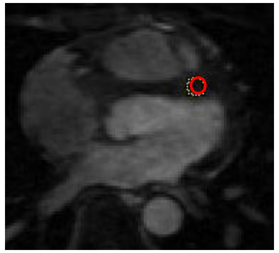
Carried out for the following regularization methods:

1) State-of-the-art method without prior information.
2) State-of-the-art method with prior information from the Q-body coil.
3) Proposed method with prior information from a median filtered pre-reconstructed image.
4) Proposed method with prior information from a mean filtered pre-reconstructed image.

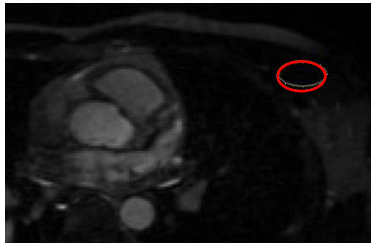
- Visual comparison: regularized images with the four methods for Tikhonov factors $\lambda_1 = 10^{-1}$ and $\lambda_2 = 10^{-2}$, the limiting ones without folding artifacts.
- Quantitative comparison: SNR and CNR measurements for Tikhonov factors $\lambda_1 = 10^{-1}$ and λ_2 between 10^{-3} and 1, the limiting ones denoising the most but without introducing folding artifacts. Taken in different tissues:



Blood



Myocardial muscle

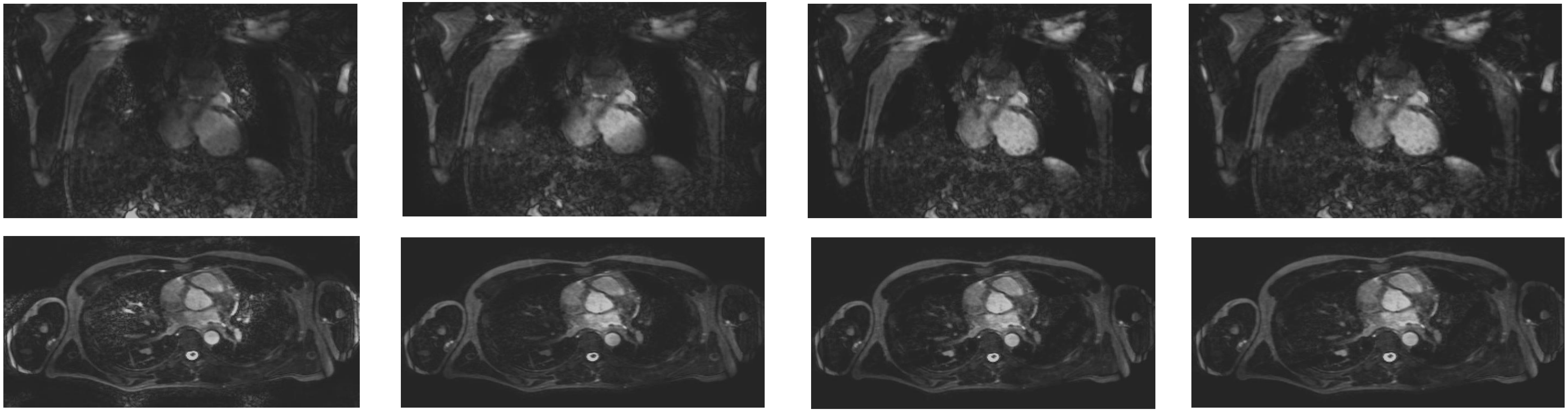


Skeletal muscle (*pectoralis*)

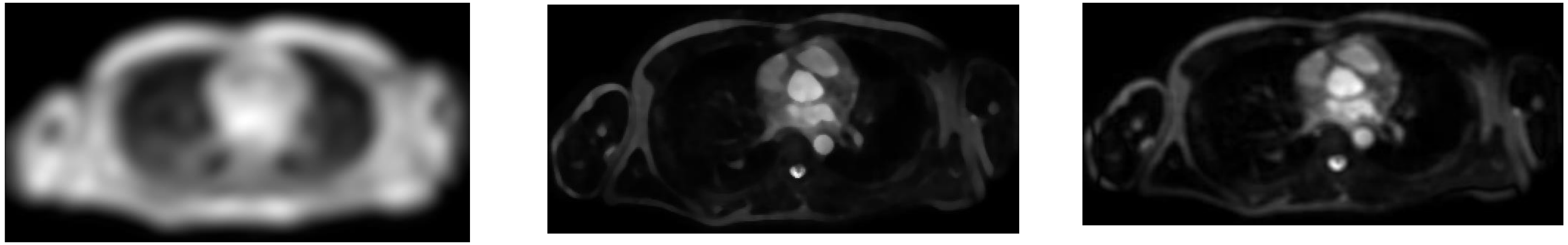
$$\boldsymbol{SNR = \frac{\mu\,(any\ tissue)}{\sigma(any\ tissue)}} \qquad \boldsymbol{CNR(tissue - blood) = \frac{\mu(blood) - \mu(myocardial\ or\ skeletal\ muscle)}{\sigma(blood)}}$$

RESULTS

VISUAL EVALUATION



PRIORS USED:



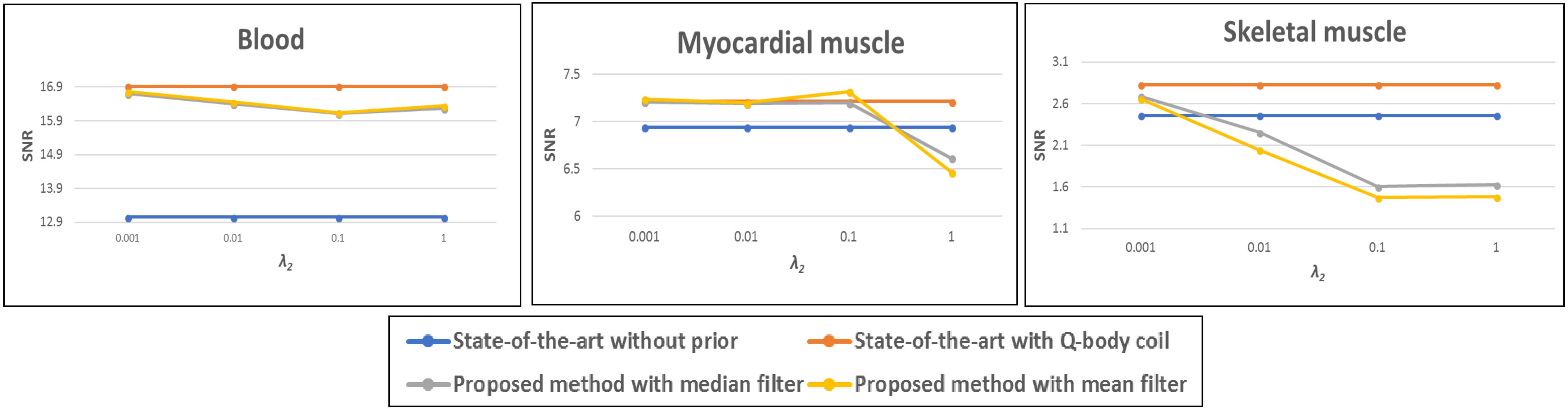
State-of-the-art without prior

State-of-the-art with Q-body coil

Proposed method with median filter

Proposed method with mean filter

QUANTITATIVE EVALUATION (SNR)



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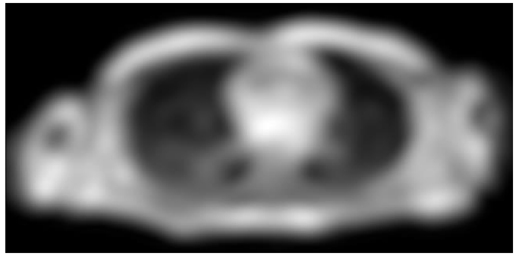
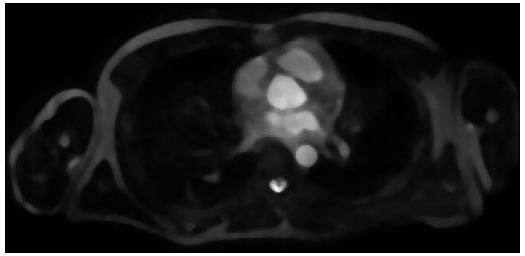
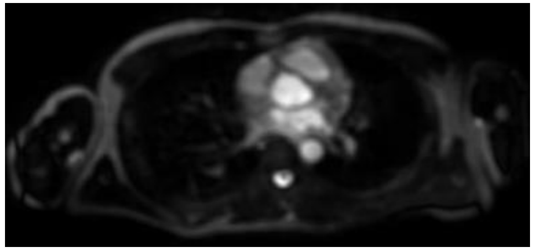


State-of-the-art with Q-body coil

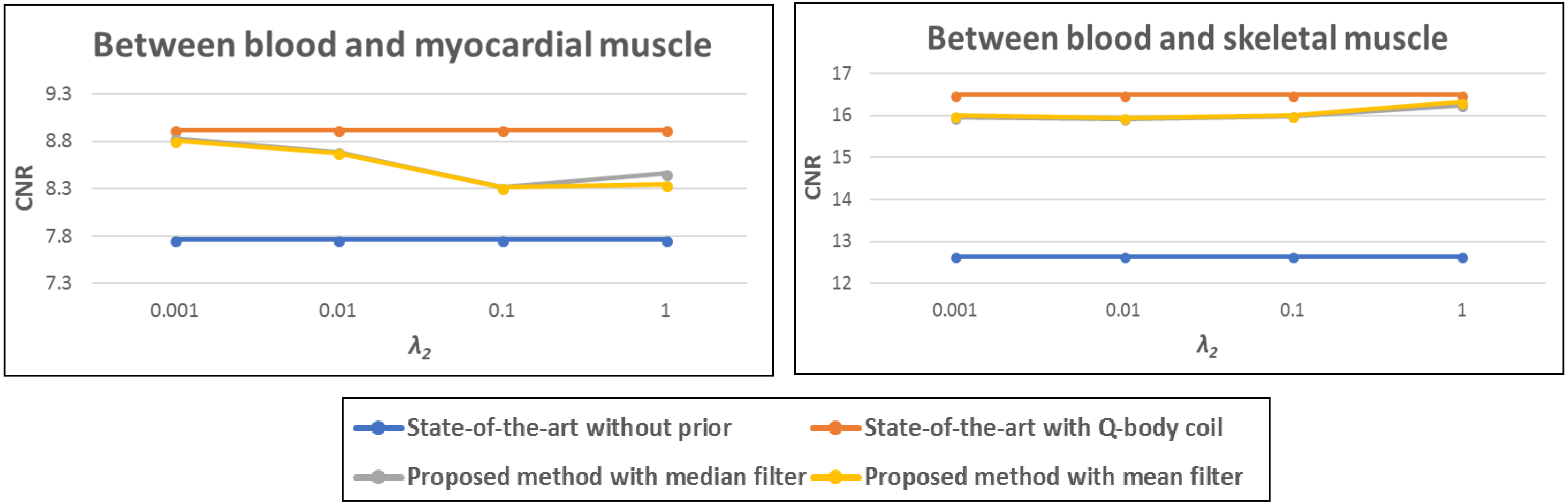


Proposed method with median filter

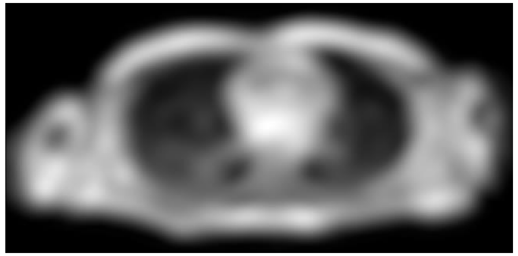


Proposed method with mean filter

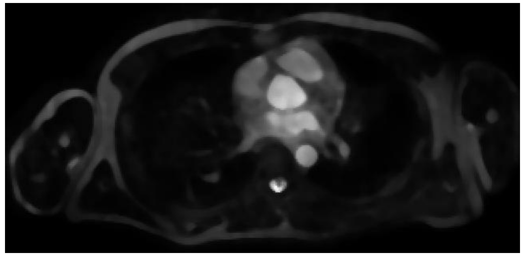
QUANTITATIVE EVALUATION (CNR)



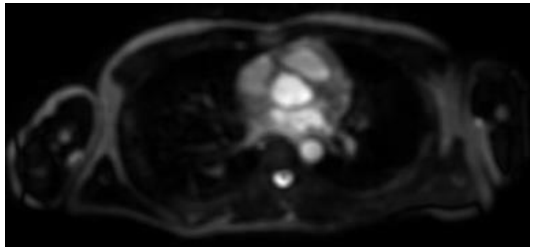
PRIORS USED:



State-of-the-art with Q-body coil



Proposed method with median filter

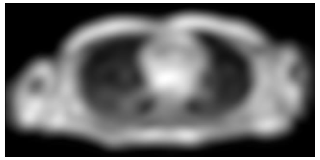


Proposed method with mean filter

DISCUSSION & CONCLUSIONS

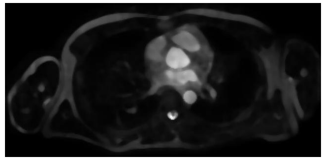
COMPARISON BETWEEN METHODS

State-of-the-art with Q-body coil prior information



1) The background noise removal of the Q-body coil regularization avoids noise propagation to the inner tissues → SNR and CNR enhancement in comparison with no using any prior

Proposed algorithm



1) Values similar to the state-of-the-art methods → Background noise removal with the new prior allowed for SNR and CNR enhancement, while attenuated tissues hardly contributed to SNR and CNR enhancement. However, some folding artifacts have been removed.

2) The algorithm is not able to totally unfold aliased voxels for λ_1, $\lambda_2 > 10^{-1}$ → folding artifacts → worse SNR and CNR than state-of-the-art methods for those λ values.

3) Results almost identical with a mean filtered prior or with a median filtered prior of the pre-reconstruction → Independent from the Low Pass (LP) filter used.

THE ALGORITHM PROVIDES SIMILAR RESULTS TO THE STATE-OF-THE-ART METHODS THAT WORK JUST WITH PRIOR INFORMATION FROM THE Q-BODY COIL → THEY DO NOT FURTHER ENHANCE SNR AND CNR.

FUTURE WORK

Short term future

Look for:

1) Applying the algorithm under higher levels of noise induced by higher SENSE factors.

2) Applying the algorithm in contrast-enhanced coronary MRA.

Long term future

- If what is tested in the short-term future is better than state-of-the-art → test the algorithm in more cases and evaluate it in an MR workstation in real time.

- If what is tested in the short-term future keeps being similar to the state-of-the-art → look for alternative regularization methods as Total Variation (TV) or Bregman regularization as substitute for Tikhonov regularization in the algorithm.

THANK YOU FOR YOUR ATTENTION!