A Novel Denoising Strategy for Ultrasound Elastography

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Military Traumatic Brain Injury Initiative

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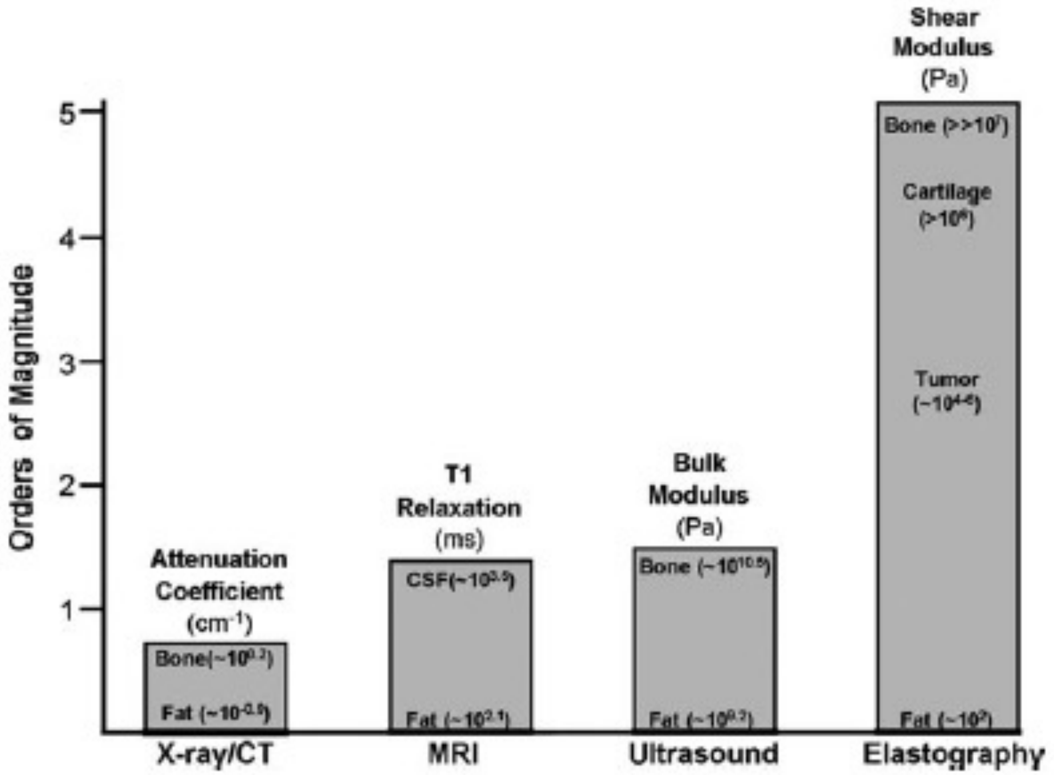
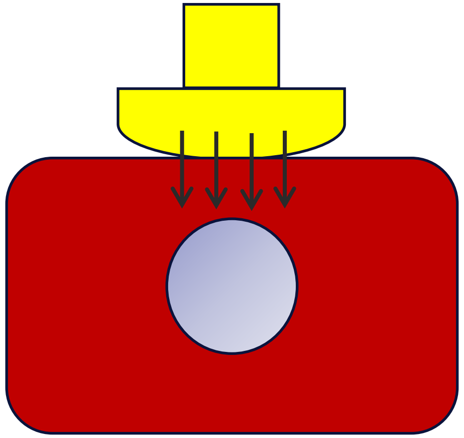
Palpation Exam

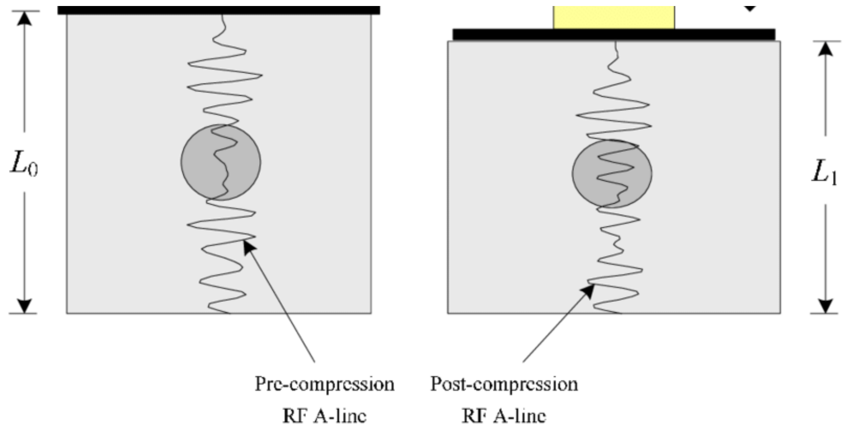


https://en.wikipedia.org/wiki/Palpation
Mariappan et al. (2010) Clinical Anatomy 23:497-511

US Elastography – General Principle

Palpate the sample → Measure the resulting displacement → Infer stiffness from the measured strain





$$\epsilon_l = \frac{\partial u}{\partial x}$$

$$\epsilon_{yy} = \frac{\partial u}{\partial y}$$

$$\epsilon_{eq} = \sqrt{\frac{2\epsilon_{ij}\epsilon_{ij}}{3}}$$

Noise amplification in the strain tensor calculation

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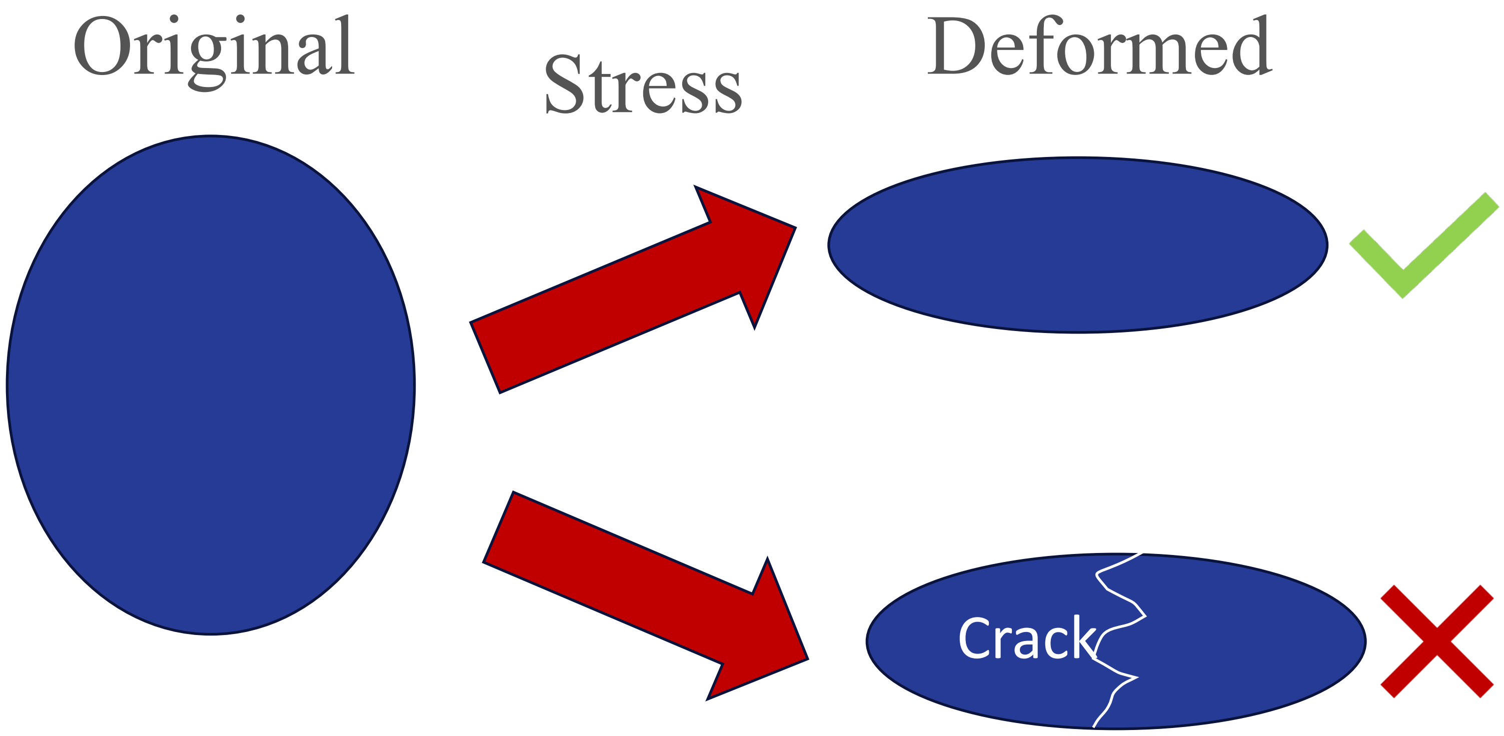
Compatibility Conditions



Strain tensor

$$\frac{\partial^2 \varepsilon_{xx}}{\partial y^2} + \frac{\partial^2 \varepsilon_{yy}}{\partial x^2} = 2\frac{\partial^2 \varepsilon_{xy}}{\partial x \partial y}$$

Enforcing the above condition on the strain tensor ensures there are **no cracks, slips, folds in the material** which the noise would mimic.

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Denoising Strategy

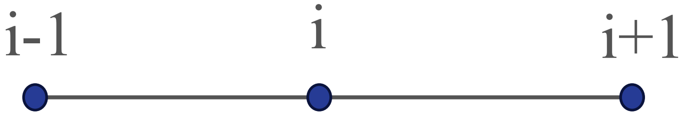
$$\min_{u} \|\vec{u} - \vec{u}_{measured}\|_2$$

s.t.

$$\left| \frac{\partial^2 \varepsilon_{xx}}{\partial y^2} + \frac{\partial^2 \varepsilon_{yy}}{\partial x^2} - 2\frac{\partial^2 \varepsilon_{xy}}{\partial x \partial y} \right| \approx 0$$

$$\varepsilon_{xx} = \frac{\partial u_x}{\partial x}, \varepsilon_{yy} = \frac{\partial u_y}{\partial y}, \varepsilon_{xy} = \frac{1}{2}\left(\frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x}\right)$$

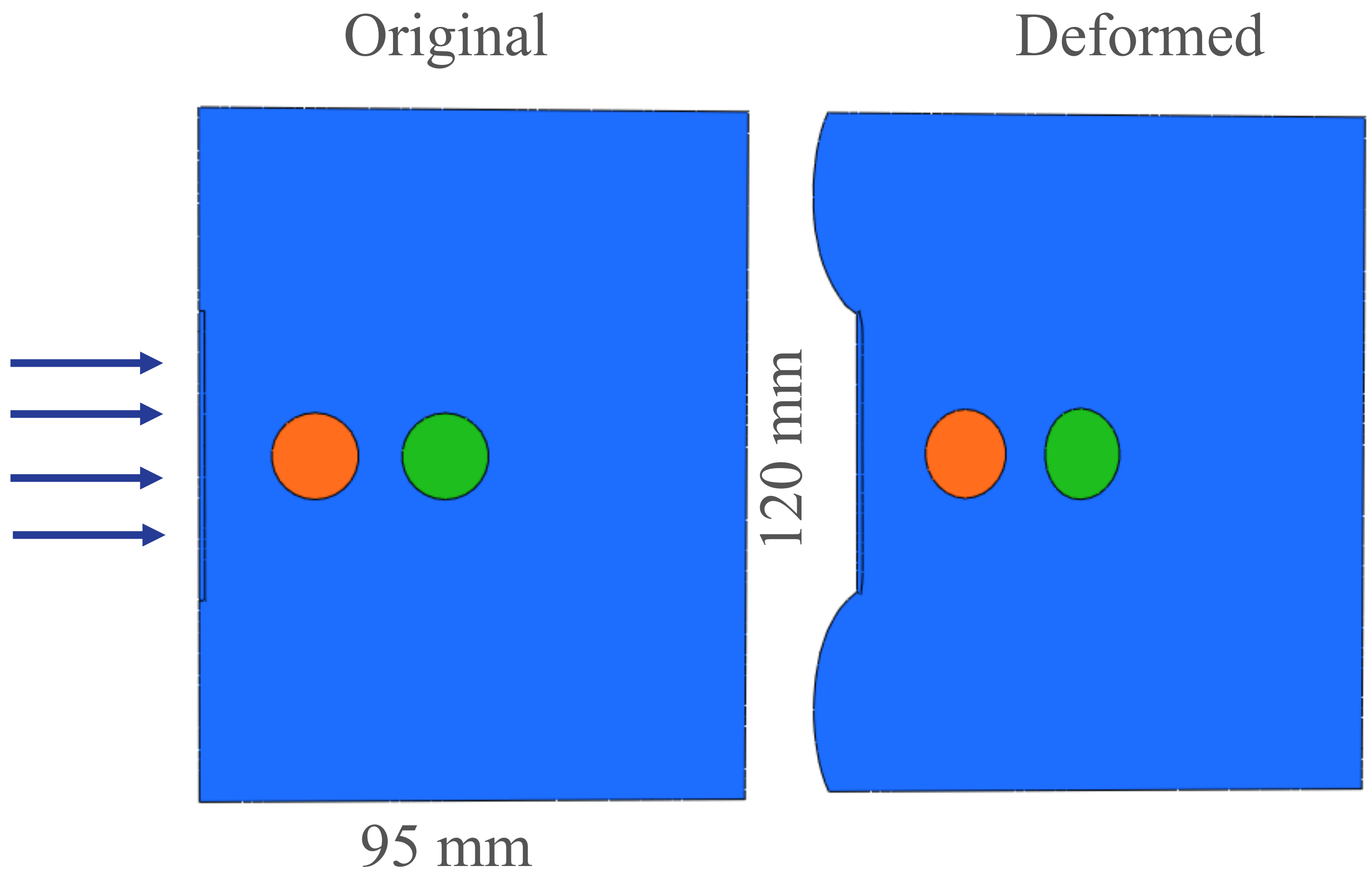
Non-linear differentiation



Essentially non-oscillatory (ENO) scheme

$$\frac{\partial f}{\partial x} = \begin{cases} \dfrac{f_{i+1} - f_i}{\Delta x} & |f_{i+1} - f_i| < |f_i - f_{i-1}| \\ \dfrac{f_i - f_{i-1}}{\Delta x} & Otherwise \end{cases}$$

Finite Element Simulation



Background
Young's Modulus 18 kPa
Poisson's ratio 0.49

Orange Inclusion (Stiff)
Young's Modulus 36 kPa
Poisson's ratio 0.49

Green Inclusion (Soft)
Young's Modulus 6 kPa
Poisson's ratio 0.49

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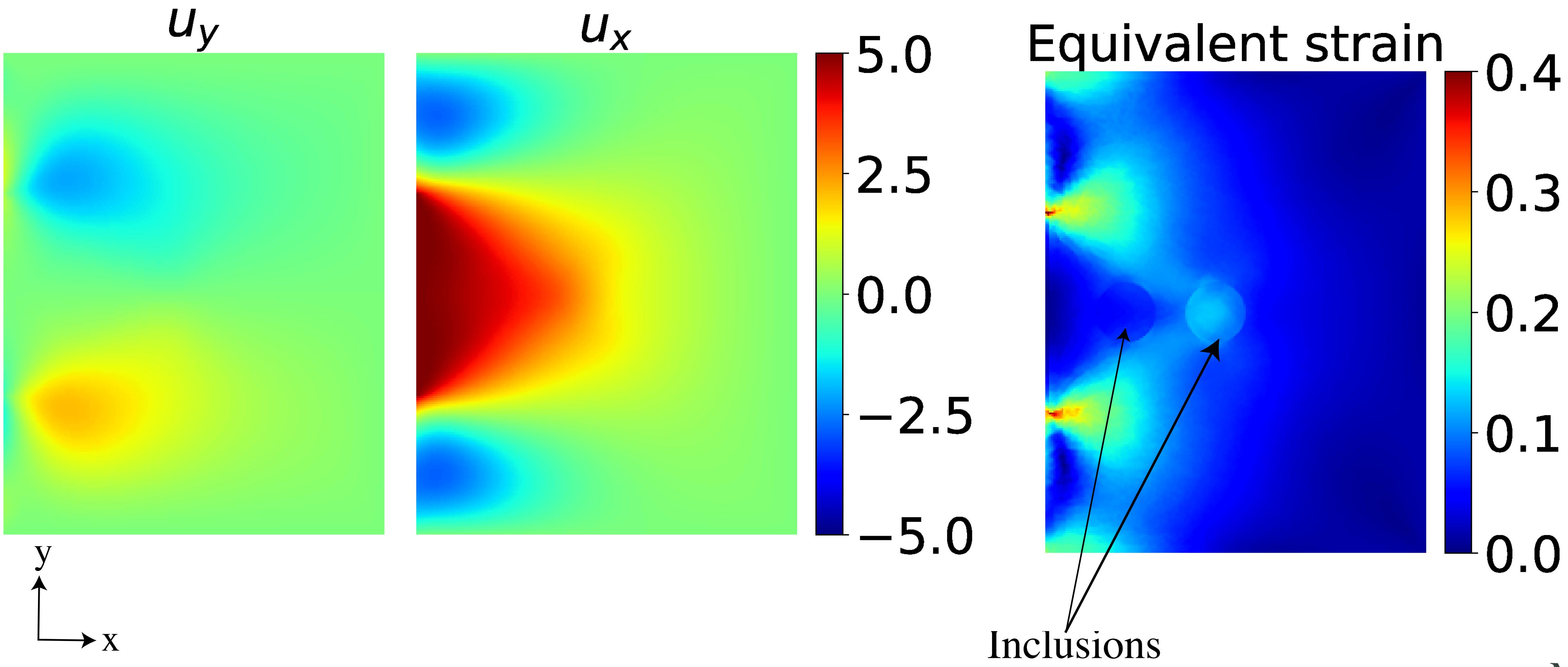
Displacement Profile & Strain



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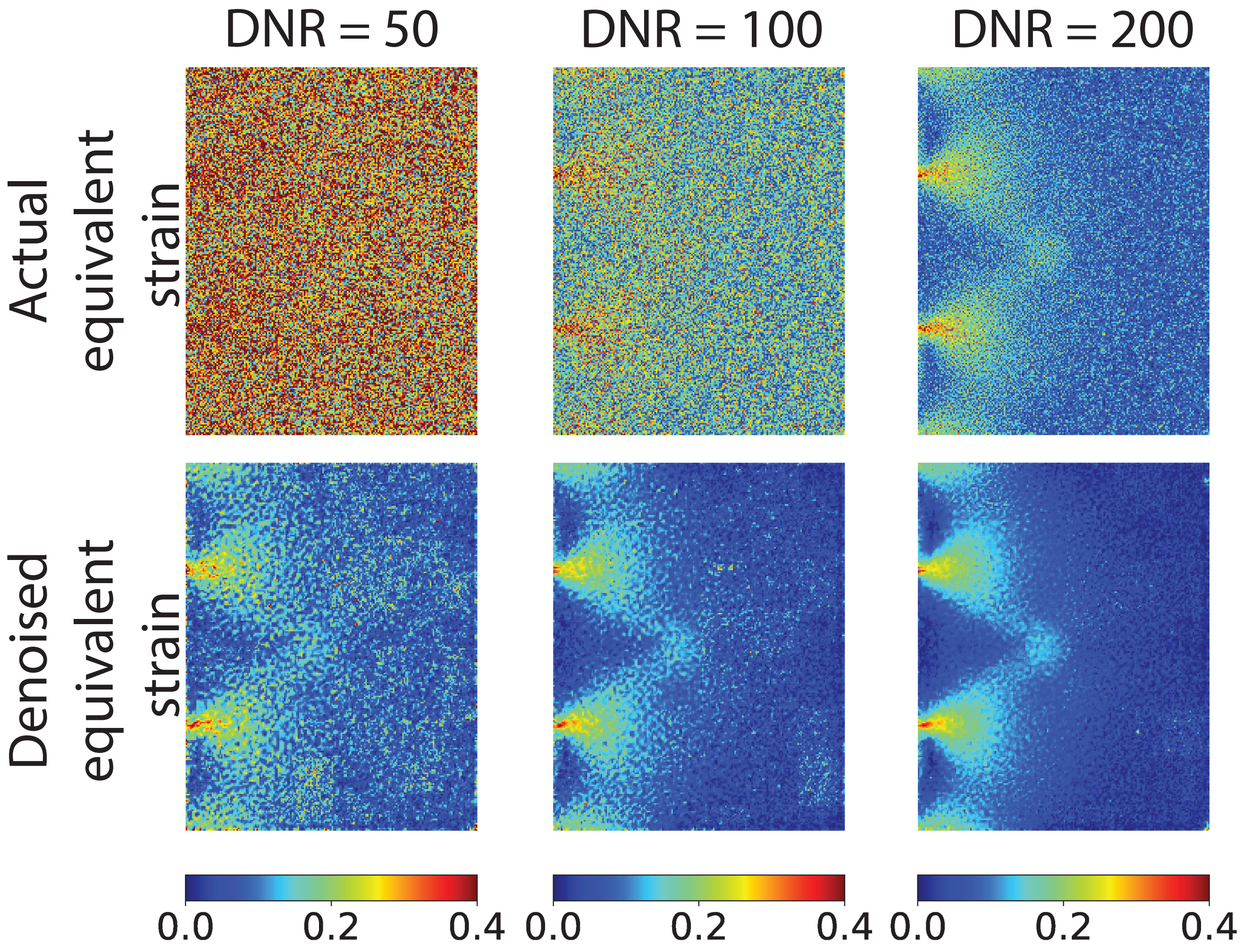
Denoising Efficacy

- Additive Gaussian noise was added to the simulated displacement field to test efficacy.
- DNR – displacement noise ratio defined as ratio of maximum displacement (5 mm) and noise standard deviation
- Contrast significantly improved with denoising



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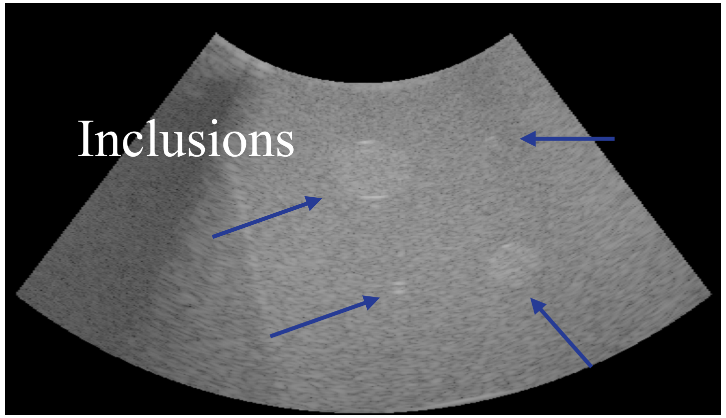
Strain Elastography Measurement

Pre-compression

Post-compression



- **Sample**: CIRS elasticity QA phantom (Model 049A)
- **US system** : Verasonics Vantage 128
- **Probe**: C5-2v (4 MHz center frequency)
- Pre- and post-compression B-mode images acquired using ray scanning.
- 2D displacement measured with speckle tracking using normalized cross-correlation of images.

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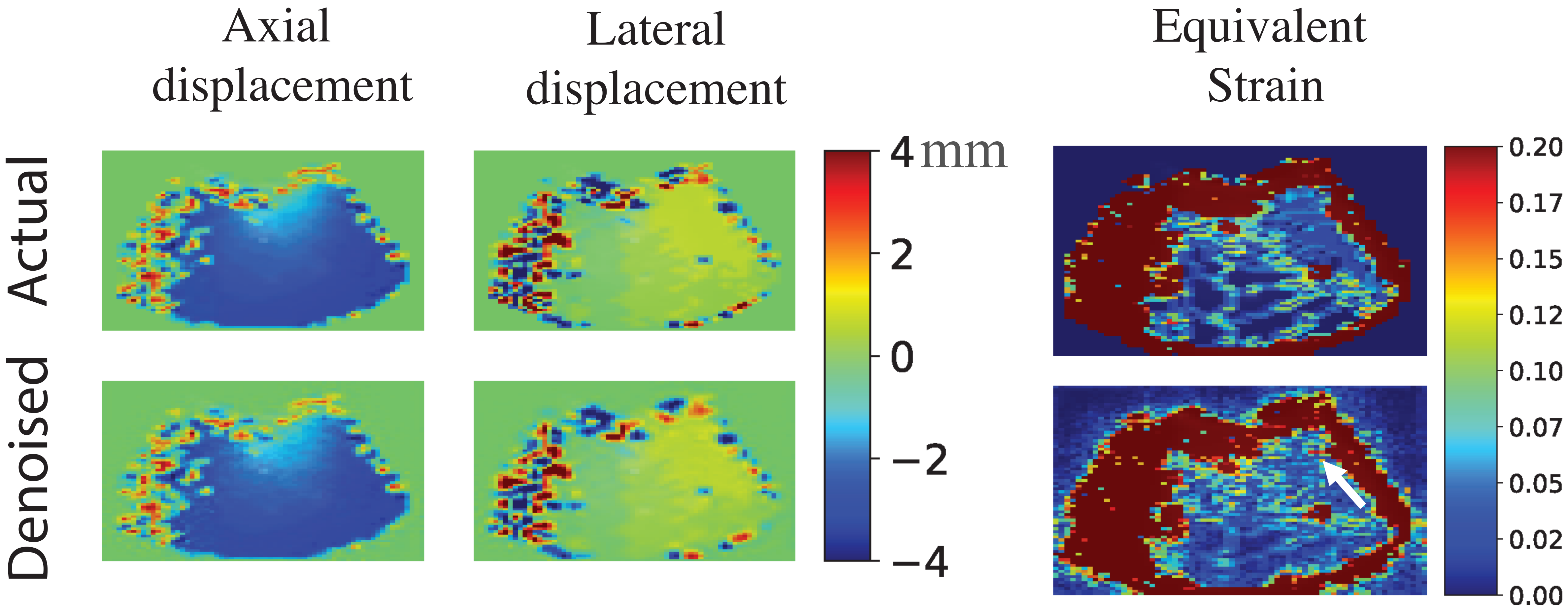
Results



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Conclusion

- We have demonstrated a novel strategy to denoise deformation fields by enforcing compatibility conditions using simulation and experimental data.
- The method is general and does not make assumptions about the material properties.
- It can be easily applied to various elastography techniques not restricted to strain elastography

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