Supplemental Material/ Appendix

HARP implementation. Strain calculations were performed using custom software written by the authors (LG and YZ) that implemented the Osman HARP method in a modular image processing framework (MeVisLab version 2.7.1, Bremen, DE). [18]

Briefly, a complex image is created using Fourier and inverse Fourier transforms of the original CSPAMM images. The phase of this complex image (harmonic phase) directly relates to the motion of the tag lines. The deformation gradient tensor is obtained from HARP images using the following equation,

$$\boldsymbol{F} = \frac{\partial \boldsymbol{y}}{\partial \boldsymbol{q}} = \left(\frac{\partial \boldsymbol{q}}{\partial \boldsymbol{y}}\right)^{-1} = \left(\left(W^T H\right)^{-1} \frac{\partial \boldsymbol{\varphi}}{\partial \boldsymbol{y}}\right)^{-1} = \left(\frac{\partial \boldsymbol{\varphi}}{\partial \boldsymbol{y}}\right)^{-1} W^T H\,, \tag{1}$$

where $\boldsymbol{q}$ is the position of a point in the image at time $t = 0$, $\boldsymbol{y}$ is the position of the same point at time t, $\boldsymbol{\varphi}$ is a vector of phases in the two tag directions, and W and H are constant matrices that can be calculated from the image. Then the 3D Lagrangian strain tensor can be calculated using,

$$\boldsymbol{E} = \frac{1}{2}\left(\boldsymbol{F}^T \boldsymbol{F} - \boldsymbol{I}\right), \tag{2}$$

where $\boldsymbol{F}$ is the deformation gradient tensor and $\boldsymbol{I}$ is the identity matrix.