Use of Constraints to Produce Plane Strain Conditions for MR Elastography

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Introduction Tissue contrast based on elastic properties has significant potential in imaging for breast cancer and other disease [1]. Since MR imaging is not directly sensitive to tissue elastic properties, quantities such as shear modulus must be calculated from measurements of displacement.

In general, tissues will deform in three dimensions during MR elastography (MRE). In order to reconstruct elastic modulus by an inverse method, 3 components of displacement must be acquired in order to establish a boundary value problem for numerical solution. Many investigators have assumed two-dimensional plane-strain conditions to analyze MRE displacement data, but it has been noted that such approximations are not very accurate for spherical inclusions [2].

However, an approximate state of plane strain can be achieved by physically constraining the material in one dimension. With simulations and experiments, we demonstrate that MRE data acquisition and analysis can be conducted in two dimensions through the use of external constraints.

Methods Simulations were conducted with a cubic object containing a spherical inclusion of modulus 2.5 relative to background. This object was discretized on a 48x48x48 mesh. A compression of 10% was simulated for with lateral constraints applied to the x_3 direction. A three-dimensional inclusion phantom was constructed from plastisol PVC (M-F Manufacturing Company, Fort Worth TX), with inclusion modulus ratio similar to that of the simulation. The phantom was placed in a MR-compatible compressor device driven by an ultrasonic motor (USR60-N4, Shinsei Corp., Tokyo Japan). Panels were positioned to constrain this object in the x_3 direction, and the motion was measured in unconstrained directions with a stimulated-echo phase contrast method [3].

Results Figure 1 shows results in the central $x_1 - x_2$ plane of the three-dimensional simulation, with constraint in the x_3 direction. The strain in the restricted direction (1c) is near zero, as clearly seen in the accompanying x_1 profiles (1d). Figure 2 shows corresponding experimental results in the same orientation. Although e_{33} was not measured experimentally, $e_{11} + e_{22}$ (2c) is a good approximation since plastisol is an incompressible material having Poisson's ratio > .499 [4]. The profiles in figure 2d show good qualitative agreement with the features of figure 1d.

Conclusions Many investigators have identified the goal of solving a three-dimensional modulus distribution with accompanying 3D displacement data set. However, even a low-resolution 3D reconstruction is a challenging numeric problem and data acquisition requirements are substantial. As an alternative, we have demonstrated with phantoms made of incompressible materials that confinement techniques may be used to produce very good plane-strain conditions, such that measurement and analysis can be conducted in two dimensions. Implementation of in-vivo confinement in breast MRE is envisioned with the chest wall as one of the constraints.

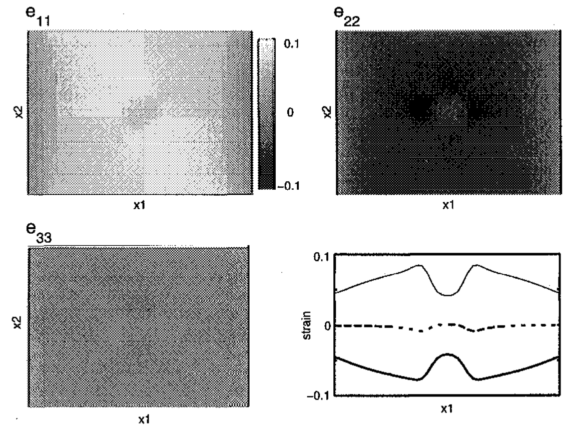

Figure 1 a-c) Simulated strain components. d) x1 profiles of e_{11} (——), e_{22} (▬▬), and e_{33} (– – –).

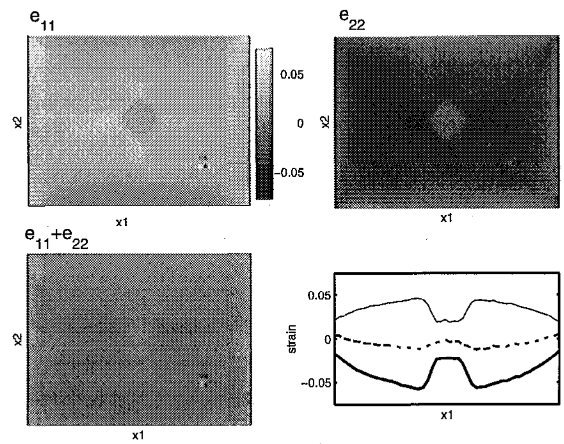

Figure 2 a-c) Experimental strain components. d) x1 profiles of e_{11} (——), e_{22} (▬▬), and $e_{11} + e_{22}$ (– – –).

References

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