

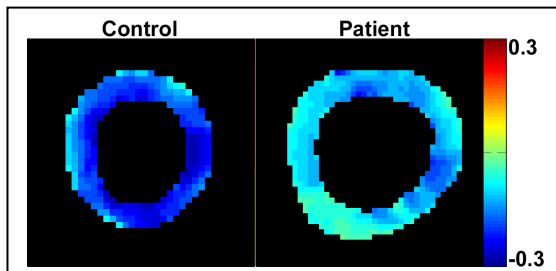
# In Vivo Validation of Fast Cine DENSE MRI for the Quantification of Regional Cardiac Function

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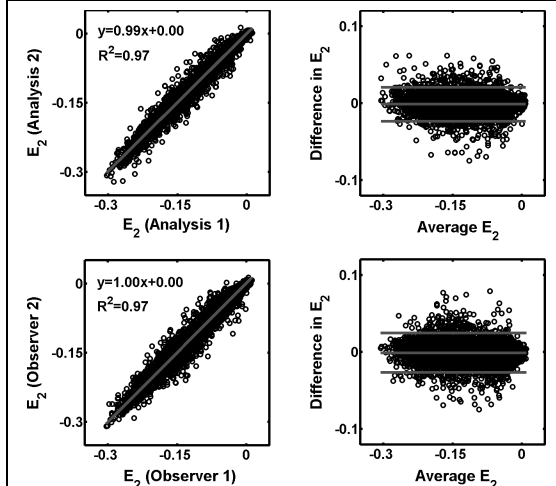
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**Introduction:** Accurate assessment of cardiac function plays an important role in the management of heart disease. Conventional imaging modalities, such as echocardiography and cine MRI, are widely used for quantitative assessment of global cardiac function and qualitative assessment of regional cardiac function. Quantitative assessment of regional cardiac function may additionally improve the accuracy of detecting subtle wall motion abnormalities due to heart disease. Recently, fast cine displacement-encoded (DENSE) MRI was developed to produce relatively high quality strain maps within clinically acceptable breath-hold duration of 12 s [1]. While this pulse sequence is promising for clinical applications, it has not been validated. Therefore, the purpose of this study was to validate the relative accuracy of fast cine DENSE MRI in controls and patients with heart disease.

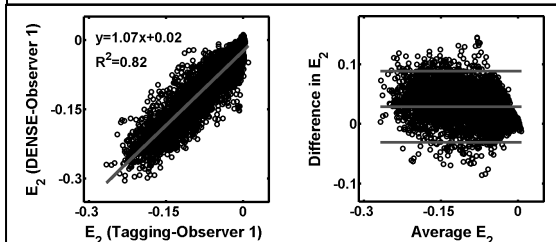
**Methods:** Myocardial tagged MRI was chosen as the reference method, because it had been validated in deformation phantoms [2, 3] and in animal imaging [4, 5]. Both the conventional tagged MR and fast cine DENSE pulse sequences were implemented on a 3T whole-body MR scanner (Tim-Trio, Siemens) equipped with a 12-channel phased array receive coil. Relevant imaging parameters for cine DENSE include: effective spatial resolution = 3.3mm x 3.3 mm, slice thickness = 7 mm, temporal resolution = 35 ms, and breath-hold duration = 12 heartbeats. Relevant imaging parameters for myocardial tagging include: spatial resolution = 1.3 mm x 1.8 mm, slice thickness = 7 mm, temporal resolution = 35 ms, breath-hold duration = 15 heartbeats, and grid tag spacing = 7 mm. Twelve healthy human subjects (7 males; 5 females; mean age = 34.5 ± 11.0 years) and thirteen patients (12 males; 1 female; mean age = 55.3 ± 11.2 years) with prior history of heart disease were imaged in three short-axis (apical, mid-ventricular, basal) planes of the left ventricle (LV), using fast cine DENSE and myocardial tagged MRI pulse sequences. For cine DENSE, cardiac contours were segmented manually by two blinded observers through the first 15 cardiac phases. Observer 1 repeated the blinded analysis after at least two weeks from the first analysis. For myocardial tagging, contour segmentation and tag tracking were performed by observer 1 through the first 10 cardiac phases. The second principal strain ( $E_2$ ), which is similar to circumferential shortening strain, was calculated. The three short-axis images were subdivided into 16 segments according to the American Heart Association standardized model [6]. For cine DENSE, the intra- and inter-observer variability was assessed by calculating the Pearson correlation coefficient ( $r$ ), intra-class correlation (ICC)[7], within-subject standard deviation (SD) and within-subject coefficient of variation (CV). The CV was expressed as a percentage of the absolute value of the grand mean. The relative accuracy of fast cine DENSE was assessed by performing Bland-Altman and linear correlation analyses on their  $E_2$  calculations.



**Fig. 1.** End-systolic  $E_2$  maps of a control subject (left) and a patient (right) measured by fast cine DENSE.



**Fig. 2.** (Top row) Intra-observer and (bottom row) inter-observer variability: (left) linear correlation and (right) Bland-Altman plots.



**Fig. 3.** (Left) linear correlation and (right) Bland-Altman plots comparing myocardial tagging and cine DENSE  $E_2$  values.

**Results:** Figure 1 shows end-systolic  $E_2$  maps of a control subject and a patient. These  $E_2$  maps demonstrate the sensitivity of fast cine DENSE to differentiate between normal and abnormal contractile function. Figure 2 shows linear correlation and Bland-Altman plots of intra- and inter-observer variability. Statistically, the intra- and inter-observer variability was 6.95% and 8.00%, respectively (see Table 1). Figure 3 shows representative end-systolic  $E_2$  maps which show good agreement between myocardial tagging and fast cine DENSE. Statistically, the two methods were strongly correlated (slope = 1.07; bias = 0.02;  $R^2 = 0.82$ ;  $n=3900$ ;  $p < 0.001$ ) and in good agreement (mean = 0.03; 95% limits of agreement = -0.03 and 0.09).

**Discussion:** This study demonstrated that fast cine DENSE MRI is highly reproducible and produces  $E_2$  measurements that are strongly correlated and in good agreement with those produced by myocardial tagging. The corresponding theoretical validation study is reported in [9]. We conclude that cine DENSE MRI is a validated method for clinical applications.

## References

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**Table 1.** Intra- and inter-observer variability statistics ( $n= 5950$ ).

|                  | Intra-Reader | Inter-Reader |
|------------------|--------------|--------------|
| Correlation: $r$ | 0.987        | 0.981        |
| ICC              | 0.987        | 0.982        |
| SD               | 0.0079       | 0.0075       |
| CV (%)           | 6.95%        | 8.00%        |