Automated Quantification of Myocardial Perfusion Based on Segmentation and Non-Rigid Registration of Contrast-Enhanced Cardiac Magnetic Resonance Images

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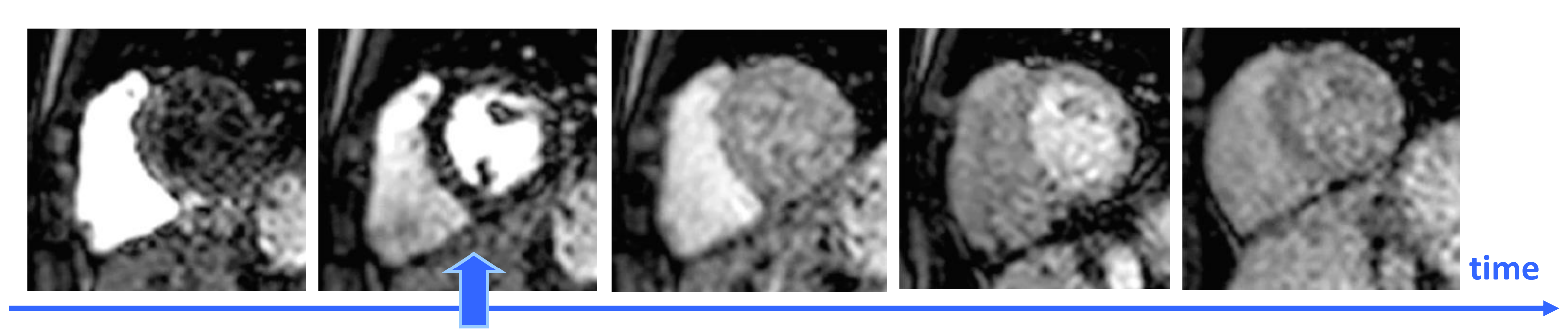
Background

- The quantification of myocardial perfusion from contrast-enhanced magnetic resonance images relies on manual tracing of regions of interest (ROIs) and their repositioning frame-by-frame throughout the image sequence.
- This tedious and potentially inaccurate methodology hinders widespread clinical use of imaging-based quantification of myocardial perfusion.
- We developed a technique for automated identification and registration of myocardial ROIs as a basis for perfusion quantification and tested its feasibility at rest and during vasodilator stress.

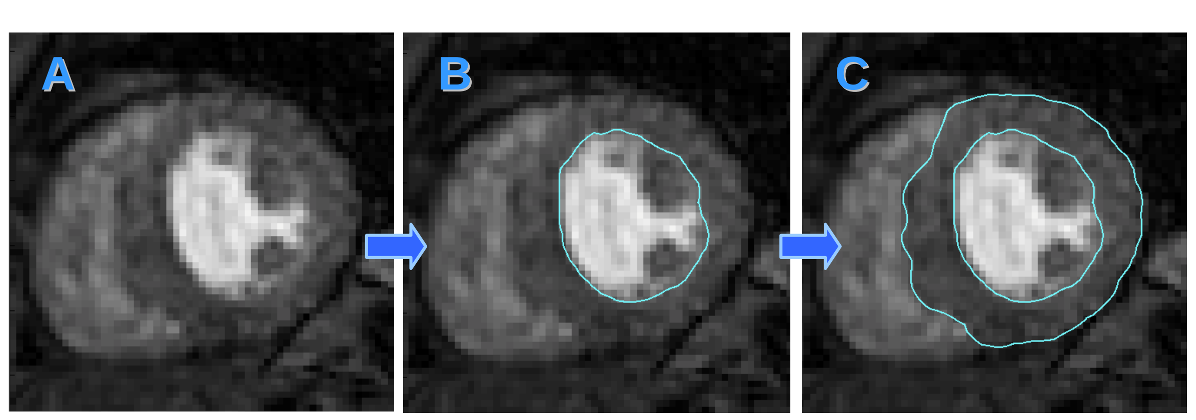
Methods

- 11 patients were studied at rest and during regadenoson stress
- 1.5 T scanner (Philips)
  - Short-axis images at 3 levels of the left ventricle
  - First pass of a Gd-DTPA bolus (0.10mmol/kg, 5ml/sec)
  - Hybrid gradient echo / echo planar imaging sequence

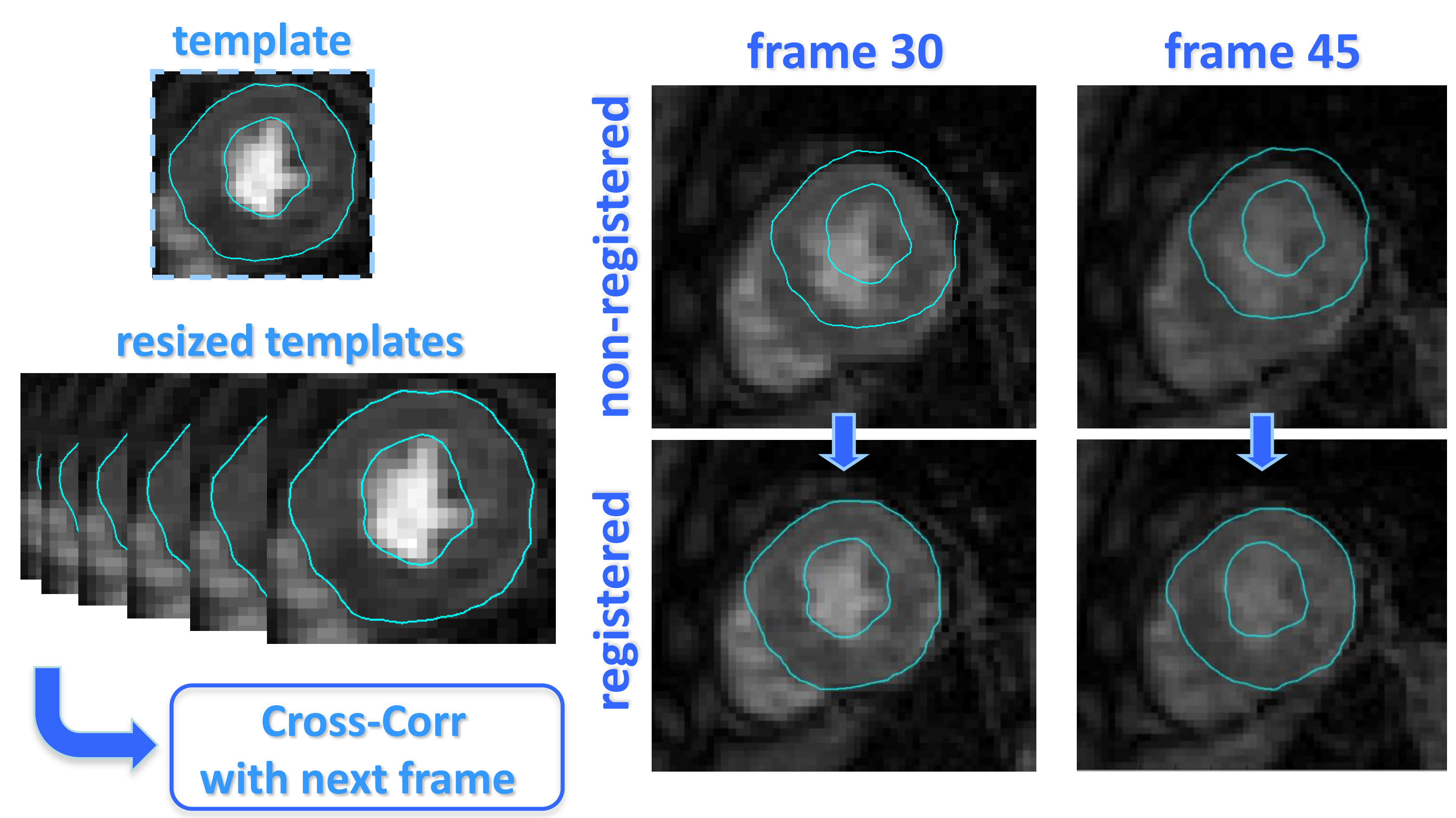
- **Image segmentation:**
  - Single seed point was manually placed inside the LV cavity
  - Best frame for endo- and epicardial detection was automatically selected:



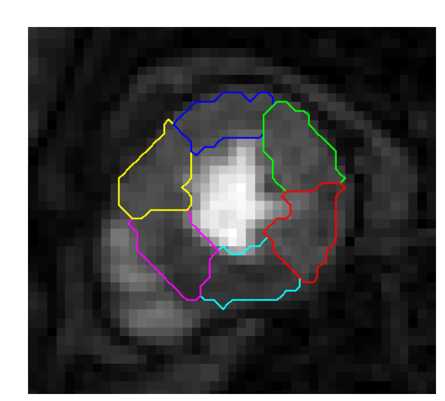
- Endocardial boundary was detected using a region-based level set technique, assuming that noise distribution in the blood pool is different from that in the myocardium.
- Epicardial boundary was then detected using a classical edge-based level-set model by searching the image from the endocardium outwards:

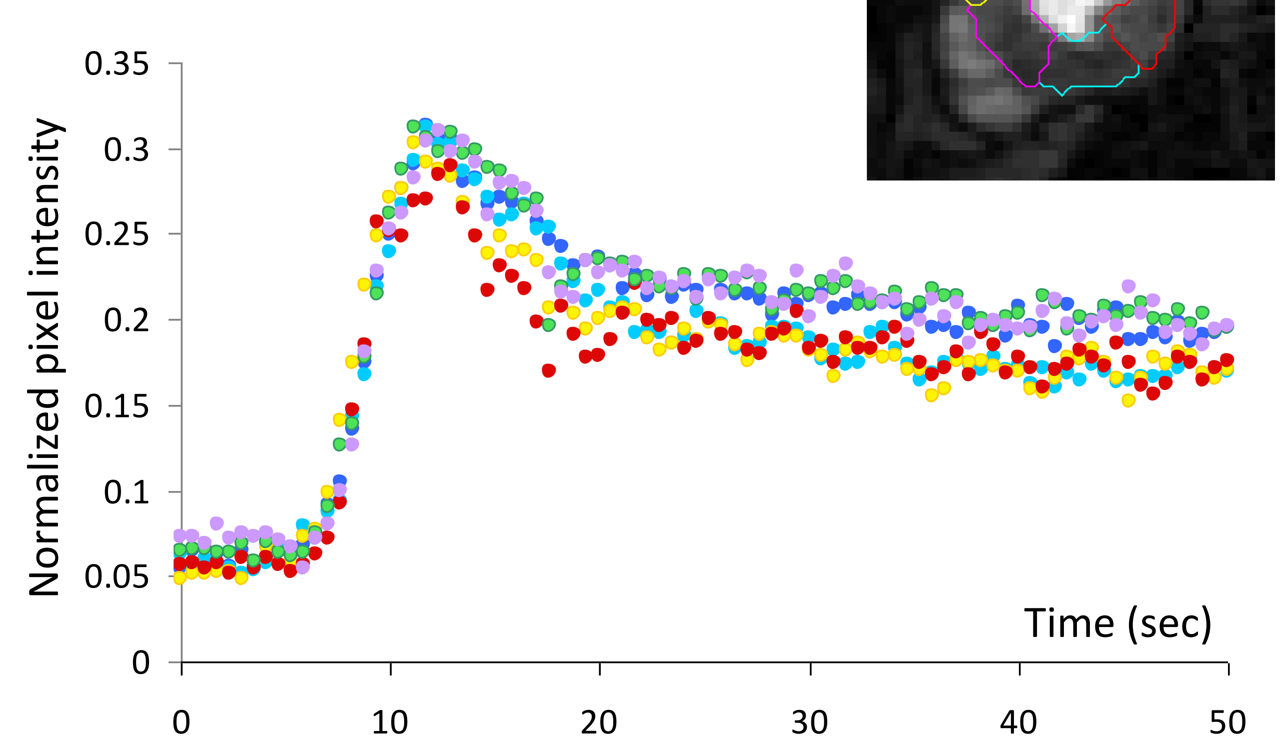


- **Image registration:**
  - Non-rigid image registration was achieved by a multi-scale extension of 2D cross-correlation to compensate for cardiac translation and deformation as a result of out-of-plane motion.
  - In each frame, endo- and epicardial contours were shifted to match the position of the left ventricle and then deformed using the edge-based level-set model to match its shape:



- **Quantification of contrast dynamics:**
  - The LV myocardium was divided into 6 wedge-shaped segments, according to standard segmentation.
  - Pixel intensity was measured in each segment over time, resulting in contrast enhancement curves.
  - From each curve, the slope of the contrast enhancement phase, reflecting the inflow rate, was calculated using linear regression analysis of the upslope portion.
  - The peak-to-peak curve amplitude, reflecting the concentration of Gadolinium per unit volume, was also calculated.

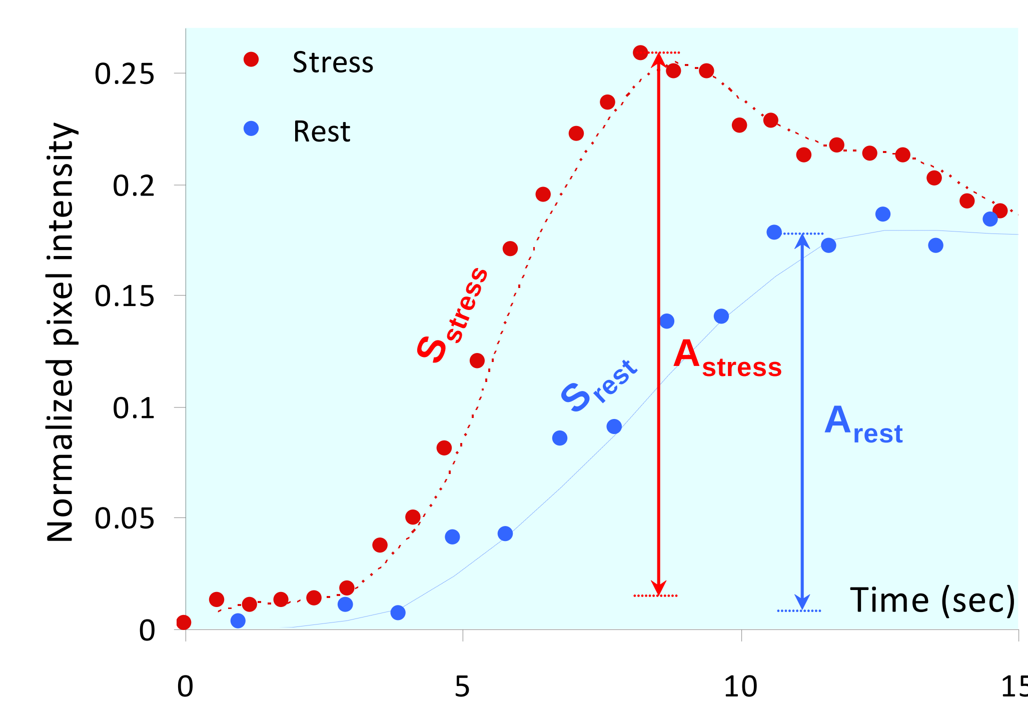




- **Performance testing:**
  - Visual frame-by-frame assessment of the accuracy of endo- and epicardial boundary positions.
  - Calculation of signal-to-noise ratio (SNR) for each segment: ratio between peak-to-peak amplitude of the contrast enhancement curve and the SD of its plateau phase.
  - Testing the ability of our technique to quantify the expected effects of stress: the slope of the contrast enhancement phase and the peak-to-peak amplitude in each segment were compared between rest and stress.

Results

- Time required for automated analysis of one slice was <1 minute on a PC and resulted in contours that were judged mostly accurate.
- Contrast enhancement curves showed the typical pattern of first-pass perfusion in all images sequences obtained at rest and stress.
- Mean SNR was 15$\pm$5 at rest and 19$\pm$4 during stress, reflecting excellent quality of the curves.
- During stress, the slope S of the upslope phase of the curves was steeper in all myocardial segments in all patients, indicating faster contrast inflow rates: 0.031$\pm$0.013 vs 0.014$\pm$0.004 sec^{-1} ($p<0.05$).
- Peak-to-peak amplitude of the curves A was also significantly higher during stress: 0.20$\pm$0.05 vs 0.14$\pm$0.03 ($p<0.05$), indicating increased intra-vascular blood volume.



Conclusions

- Despite the extreme dynamic nature of contrast-enhanced image sequences and respiratory motion, fast automated detection of myocardial segments and quantification of tissue contrast result in curves with excellent noise levels, which reflect the expected effects of stress.