Quantitative Assessment of the Dark Rim Artifact in First Pass Perfusion Images: Effect of Stress and Rest, and Sequence Dependence

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Introduction

Perfusion quantification by cardiac magnetic resonance first-pass imaging assumes a linear dependence of image intensity on the concentration of contrast agent (CA). However, myocardial signal intensity can be compromised by the presence of artifacts. The presence of the DRA in cardiac perfusion images impacts negatively on the quantification of myocardial perfusion for the detection of ischemic heart disease. The artifact appears as signal loss in a rim of pixels at the endocardial boundary between the myocardium and LV blood. The signal loss occurs after the arrival of CA in the LV, and occurs at the same time as the CA bolus passes through the LV cavity. The DRA has been reported in single shot TFI and TFL first pass perfusion images, but its origin is poorly understood. It may be caused by a combination of factors including altered susceptibility from high CA concentration. This report quantitatively evaluates the DRA in Gadolinium enhanced first pass perfusion TrueFISP (TFI) images acquired under stress and at rest, and compares the artifact severity and frequency using TFI, TurboFLASH (TFL) and echo planar imaging (EPI) pulse sequences.

Method

Images from two separate studies approved by the institutional review board were analyzed for artifacts. In the first study, images were acquired in 14 normal volunteers (10 female) age 43.8 (s.d. 15.9) years, using a saturation recovery TFI pulse sequence and Gadodiamide (0.05 mM/kg), under adenosine (140 ug/kg/min) stress followed by rest scans. The imaging parameters were as follows: TFI(TR 160 ms, TE 1.03 ms, FA 50, matrix 192 x 108); three long axis planes (HLA, VLA, and LVOT) of 8 mm slice thickness were recorded. In the second study, images were acquired using the dual bolus approach with two doses of Gadodiaminde (0.005 and 0.05 mM/kg) at rest from 11 normal volunteers (5 female) using the TFI (TR 199 ms, TE 1.04 ms, FA 50, matrix 192 x 160), TFL (TR 163 ms, TE 1.27 ms, FA 10, matrix 192 x 160) and EPI (TR 5.8 ms, TE 1.22 ms, FA 25, matrix 160 x 132) pulse sequences in random order during a single session. Three long axis slices and a mid-ventricular short axis slice, all with a slice thickness of 10 mm, were recorded for each pulse sequence. Images were analyzed for the presence of DRA using ImageJ to measure the intensity profile across the myocardium as shown in Figure 1. Data were analyzed and displayed using Microsoft Excel as shown in Figure 2. DRA was identified in images showing signal loss in the subendocardium occurring after the arrival of the CA in the LV and showing duration coincident with the passage of the bolus through the LV. The DRA was defined as 20% or more decrease in image intensity in the subendocardium relative to the rest of the myocardium across the profile in the same frame. The severity of the DRA is the percentage signal loss in the artifact relative to adjacent myocardium in the same image. The frequency of occurrence is the percentage of images with artifacts in a series of 50 images.

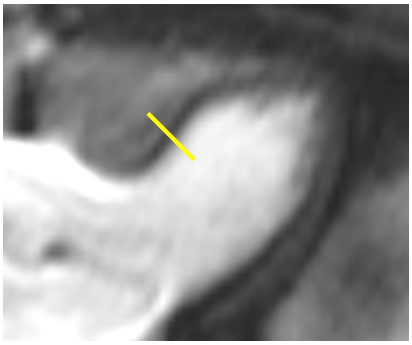
Results

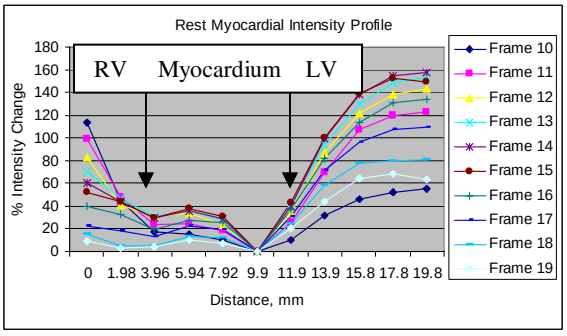
Stress and Rest: Both rest and stress images are affected by the DRA with significantly different ($p = 0.012$) frequencies: 286 or 13.6 % (rest) and 233 or 11.1% (stress) of the total of 2250 images show DRA. The difference in frequency is attributed to the very significant difference ($p < 0.001$) in heart rate which shows a mean of 61.4 (s.d. 6.1) beats per minute (bpm) for rest and 85.7 (s.d. 15.2) bpm for stress. The mean signal loss per image is 32.3 % ± s.d. 9.4% (rest) and 31.8 % ± s.d. 9.9% (stress). The range of signal loss ion rest images was 26-90% (s.d. 15.8%) while the range of signal loss in stress images was 22-84% (s.d. 15.2%). For both stress and rest, the images showing the most severe DRA correspond with the greatest CA concentrations in the LV as shown in Figure 3.

Sequence dependence: DRA was found in TFI images from 8 of 11 volunteers (4% of all images), while only 3 sets of TFL (2%) images contained the DRA. The EPI sequence which has the shortest TR of 5.8 ms produced no artifacts suggesting that temporal resolution plays a significant role in the formation of the DRA. The severity of the DRA is similar for TFI and TFL images with a mean signal loss of 31.6 % (s.d. 8.6%) and 33.1% (s.d. 5.2%) respectively. The average duration of the DRA is also similar for TFI and TFL with 11.4 (s.d 3.4) and 10.5 (s.d. 1.3) frames out of 50 respectively showing the artifact. There were no artifacts in low CA dose (0.005 mM/kg) images suggesting that there might be a threshold concentration above which signal loss occurs.

Conclusions

The severity of the DRA is similar in stress and rest TFI images implying that the artifact is independent of heart rate. The DRA appears most often in TFI images, and with less frequency in TFL images, but severity and duration are the same for both pulse sequences. No DRA was found in EPI images, suggesting that the temporal resolution plays a significant role in the formation of the artifact. The absence of the DRA from low CA dose images and the association between of the severity of the DRA and high CA concentrations in the LV in TrueFISP images suggests that the susceptibility difference at the boundary between blood and myocardium contributes to the formation of the artifact.





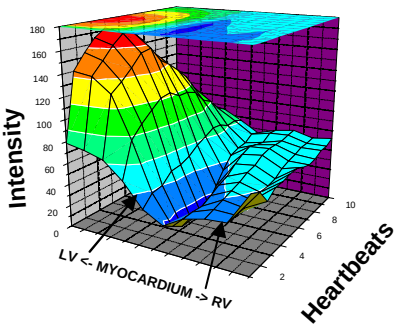


Figure 1 (left): LVOT view in a rest image showing the line across the myocardium used to extract the intensity profile. Figure 2 (center): Graph of the intensity profile in a series of 10 consecutive image frames for rest. Figure 3 (right): Time evolution of the artifact showing that severity of signal loss in the DRA coincides with the highest concentrations of CA in the LV.