

## Perceived dark rim in first-pass myocardial perfusion MRI due to visual illusion

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**Introduction:** First-pass myocardial perfusion imaging is plagued by artifactual dark rim that appears in healthy sub-endocardium. This dark rim artifact (DRA) is often the reason for false positives, and for lower diagnostic specificity than sensitivity [1]. Gibbs' ringing and motion during data acquisition have been identified as sources of DRA [2,3]. This study presents evidence of another source of perceived DRA, which is associated with human visual illusion. We demonstrate that dark rim can be perceived solely by visual illusion in the absence of true signal dip, using numerical phantoms and in-vivo perfusion images.

**Methods and Results:** Simulation: A dynamic numeric phantom was constructed in Matlab (see Fig 1). Temporal intensity changes for the LV, RV, and myocardium matched data from an actual in-vivo perfusion scan. The myocardial thickness was 3.2 pixels, which is equivalent to 3.1 mm spatial resolution for a 1cm myocardial thickness. The  $k$ -space data were Hanning windowed to suppress Gibbs' ringing [2] and 5-fold zero-padded to avoid the artifacts due to sub-pixel shifts [5]. Fig. 1 shows gray scale images of the heart phantom at four time frames from peak LV enhancement through peak myocardium enhancement (9.6 s, 12.4 s, 15.2 s, 17.8 s from the pre-contrast phase). While there is monotonic intensity change across the LV-myocardium border (black arrows), a dark rim is still perceived (white arrows). This is due to a well-known visual illusion called the Mach band effect [7].

In-vivo Experiments: In-vivo perfusion images were acquired from two healthy volunteers (40M, 54M) on a 3T GE Signa scanner. Imaging parameters were  $T_{SR} = 120$  ms,  $TR = 2.8$ - $3.2$  ms,  $TE = 1.0$ - $1.2$  ms, spatial resolution =  $2.5 \times 3.1$ - $3.3$ mm<sup>2</sup>, rate-2 TSENSE reconstruction [4], and 0.05 mmol/kg contrast agent (Multi-hance). The same Hanning windowing and zero-padding as in the simulation study were applied. Images were rendered in conventional gray scale and also in color scales with six different luminance contrasts using an empirical formula for the luminance of a RGB color:  $0.3R+0.59G+0.11B$  [6]. The color images were ranked by 2 cardiologists in terms of (i) strength of perceived dark rim, and (ii) contrast sensitivity (perceptual spatial resolution). Fig. 2 contains in-vivo images at the same time spacing as in Fig. 1. Dark rim is perceived along inferior and lateral wall (white arrows). Four intensity profiles across the sub-endocardial border (only two shown at the bottom row) on each of inferior and lateral walls demonstrate the absence of quantitative signal dips, suggesting that the perceived dark rim is a visual illusion. Fig 3 contains the same data as the second column in Fig 2, displayed by color maps with increasing luminance contrast from the left to the right. Subjective rankings of contrast sensitivity and the presence of illusory dark rim increase as luminance contrast increases, but this trend is not completely monotonic.

**Discussion:** Sub-endocardial dark rim in first-pass perfusion images can also be a result of visual illusion. Numerical phantom and in-vivo images have shown to exhibit illusory dark rim in the absence of any true signal dip. Color visualization of perfusion images can provide a flexible tradeoff between illusory dark rim and perceptual spatial resolution. A favorable tradeoff remains to be investigated by psychophysical tests on large sets of color scales.

**References:** [1] SD Wolff et al, *Circ* 110: 732-737, 2004. [2] EVR Di Bella et al, *MRM* 54:1295-1299,2005. [3] P Storey et al, *MRM* 48:1028-1036, 2002. [4] P Kellman et al, *MRM* 45: 845-852, 2001. [5] P Ferreira et al, *JCMR* 11:17, 2009. [6] ITU-R, *Recomm.* 601, 1982. [7] L Pessoa, *Vision Res* 36:3205-3227, 1996.

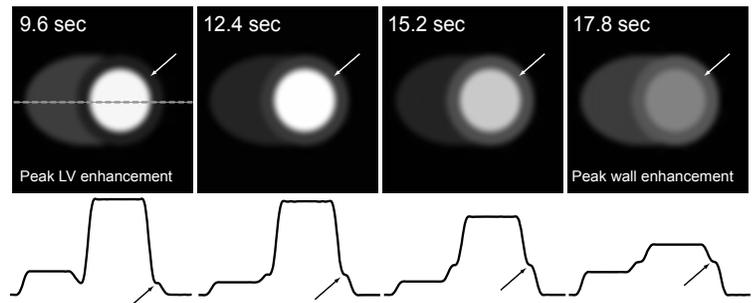


Figure 1. Numerical heart phantom and 1D intensity profiles along the dotted horizontal line.

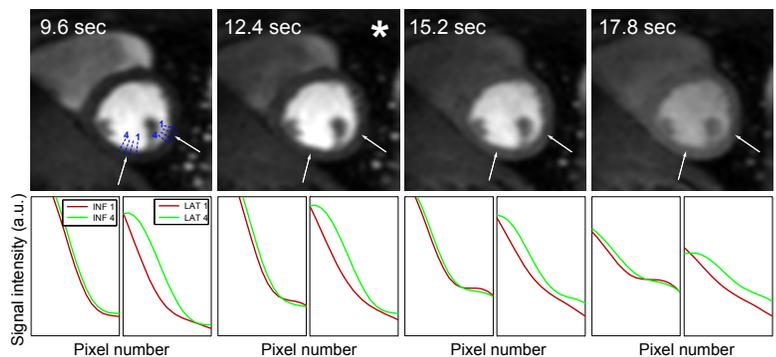


Figure 2. In-vivo perfusion images and transmural intensity profiles along the blue lines (two profiles shown per each of inferior and lateral regions).

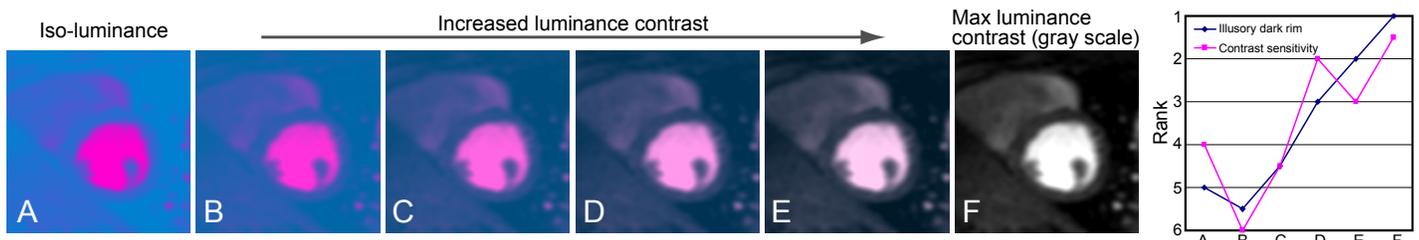


Figure 3. Color display of the data from Figure 2\* using six different luminance contrasts and ranking results of the six color images.