Can Simultaneous Antegrade/Retrograde Cardioplegia Protect the Myocardium Distal to a Coronary Occlusion?
Localized $^{31}$P MR Spectroscopy, MR Imaging and Fluorescence Imaging Studies on Isolated Pig Hearts

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INTRODUCTION
Simultaneous antegrade/retrograde cardioplegia (SARC) has been proposed to improve myocardial perfusion in the areas distal to a coronary lesion (narrowing or complete occlusion). However, no study has demonstrated that SARC can sustain normal myocardial energy metabolism. Moreover, it is unclear how the occluded myocardium is perfused by SARC. This study was designed to address these questions.

MATERIALS AND METHODS
Twelve pig hearts were used to study the effects of SARC on myocardial energy metabolism. Following 30 mins of control perfusion, pig hearts were arrested with antegrade cardioplegia (AC) for 10 mins. Subsequently, the left anterior descending coronary artery (LAD) was occluded for 20 mins to induce reversible injury. The pig hearts were then subjected to either SARC ($n=6$) or AC ($n=6$) for 50 mins while the LAD remained occluded, followed by 30-min reperfusion. A 1.5-cm in diameter surface coil was position over the LAD region.

Localized $^{31}$P spectroscopy was performed throughout the protocol using a 7T system (Bruker Avance). For each spectrum 60 FIDs were accumulated over a 2-min period. Myocardial perfusion by SARC in the occluded region was assessed by monitoring the distribution of Gd-DTPA (1.0 mmole) injected into either the aorta or the coronary sinus ($n=8$). How SARC perfused the occluded myocardium was determined by following the pathway of a fluorescent dye (200-500 μl of 51 mM indocyanine green) administered during SARC into either the aorta or the coronary sinus (CS, $n=4$) using fluorescence imaging.

RESULTS AND CONCLUSIONS
Occlusion of the LAD during AC resulted in a significant decrease in PCr and an increase in Pi (Figure 1). The ischemic changes continued in the hearts subjected to AC. In contrast, SARC resulted in a rapid recovery of Pi and PCr levels. This demonstrates that flow delivered to the occluded areas of the myocardium by SARC is sufficient to sustain normal myocardial energy homeostasis. In addition, T1 images showed a gradual increase of signal intensities in the LAD region regardless of whether Gd-DTPA was injected into the aorta or the CS, suggesting that the occluded myocardium is perfused by blood delivered from both aorta and CS during SARC (Figure 2). Furthermore, the fluorescence images obtained during SARC showed that only the coronary veins in the LAD region contained the fluorescent dye even when the dye was injected into the aorta. We conclude that (1) SARC can maintain myocardial homeostasis; (2) blood delivered through both arteries and veins can reach the occluded areas of the myocardium; (3) blood delivered via the patent arteries reaches the occluded myocardium through vein-vein anastomoses, not artery-artery anastomoses.

![Figure 1. Time course of PCr and Pi with SARC and AC](image1)

![Figure 2. Signal intensities of T1-weighted images obtained from the LAD region during SARC with Gd-DTPA injected into the aorta (panel A) or the coronary sinus (panel B).](image2)

![Figure 3. Fluorescence images obtained with antegrade cardioplegia during venous phase (A) and during SARC with fluorescence dye injected into the aorta (B) or coronary vein (C), respectively.](image3)