EVALUATION OF CARDIAC FUNCTION USING NONINVASIVE PHASE-CONTRAST MRI, CINE MRI AND INVASIVE PRESSURE-VOLUME TECHNIQUES ON PIGS AT REST AND UNDER PHARMACOLOGIC STRESS TEST

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OBJECTIVE: To validate noninvasive cardiac output measurement techniques of phase-contrast magnetic resonance imaging (PC-MRI) and cine MRI using an invasive pressure-volume (PV) loops analysis on a swine model at rest and under pharmacologic stress conditions.

INTRODUCTION: Congestive heart failure is a cardiac syndrome that occurs due to severe decrease of left ventricular (LV) contractility. The condition of the heart can be determined by its level of contractility to circulating blood flow at an adequate rate within a body. Existing techniques for assessment of LV function are classified into two major categories: **invasive** (i.e., direct) measurements using a conductance catheter [1] and **noninvasive** (i.e., indirect) estimations that use imaging techniques [2,3]. Previous work has shown that analysis of the time-varying curve of instantaneous pressure (P) to volume (V) obtained from an indwelling conductance catheter yields accurate assessment of intrinsic ventricular diastolic and systolic properties independently of loading conditions [4]. However, PV loop analysis is an invasive procedure that makes it difficult to perform routinely on patients. PC-MRI has recently been demonstrated as a noninvasive alternative for measurement of blood flow in a wide spectrum of cardiovascular pathologies. PC-MRI provides unique advantages for noninvasive diagnosis because of the absence of ionizing radiation exposure, high reproducibility, and the ability to perform integrated assessments of anatomy and function of the heart for patients. Alternatively, fast steady-state gradient-echo cine techniques have been widely used in clinic to evaluate cardiac outputs through acquisition of short-axial cine images of the LV. To our knowledge, the accuracy of the cardiac MRI techniques has not been validated by comparison with traditional invasive PV loop measurements with and without dobutamine stress test. The aim of our study was to determine the accuracy and reliability of PC-MRI and cine MRI for measurement of cardiac output by comparing the results obtained from these methods to those yielded by the current invasive gold standard (i.e., PV loop).

METHODS: We compared three methods for evaluating cardiac function at rest and under pharmaceutical stress conditions: (i) PC-MRI, (ii) cine MRI and (iii) PV loop. These measurements were made in fourteen domestic pigs at rest conditions. Identical MRI acquisitions and PV loop analysis were performed on six pigs from the same group that received an infusion of dobutamine 2.5 μg/kg/min. Cardiac outputs from all measurements were analyzed and compared using linear regression and Bland-Altman analysis. **PV loops:** The left carotid artery was isolated and instrumented with a 5F/7-electrode conductance catheter advanced into the LV to perform *in vivo* PV loop measurements. A 2-inch incision was made on the abdomen for access to the inferior vena cava to control cardiac pre-load. All physiologic parameters (LV pressure, LV volume, heart rate, and peak rate pressure development, dP/dtmax) were monitored and recorded using a commercial PV loop system (Millar Instruments, Inc., Texas, USA). **MRI:** Through-plane flow measurements using PC-MRI were used on an imaging plane perpendicular to subjects' descending aorta. The acquisition parameters of PC-MRI were: image matrix=256x144,spatial resolution =2.18x2.18mm^2,VENC=150cm/sec, and TE/TR/temporal resolution=2.6/7.1/42.0msec. Alternate MRI measurements of cardiac output using a segmented cine spoiled gradient-echo sequence were performed in contiguous short-axis locations, parallel to the tricuspid valve annulus, spanning the LV from base to apex. Imaging parameters of cine MRI were: image matrix=196x108, spatial resolution=2.84x2.9mm^2, and TE/TR/temporal resolution=2.6/6.8/34 msec. Nine to twelve slices were acquired, with a slice thickness of 8 mm and 2-mm gap between slices on short axis images.

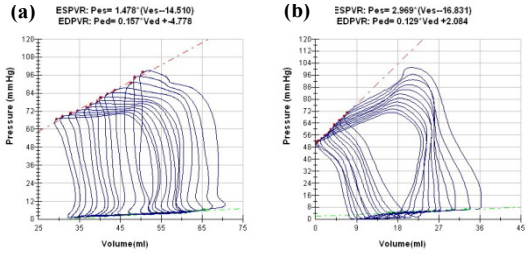

Figure 1. Representative plot of LV PV loops of one pig (a) at rest and (b) under stress conditions. The slops of end-diastolic pressure volume relation (EDPVR) and end-systolic pressure volume relation (ESPVR) were calculated for evaluation of cardiac contractility

RESULTS: Figure 1 shows the PV loop results at both resting and stress conditions on one pig. Measurements using PC-MRI and cine MRI show similar results of cardiac output measurement compared to an invasive PV loop technique under both rest (PC-MRI, cine MRI and PV loop, 3.17±0.45, 3.18±0.61, 3.45±0.41 L/min, respectively) and pharmaceutical stress conditions (PC-MRI, cine MRI and PV loop, 4.78±0.53, 4.7±0.6, 4.96±0.48 L/min, respectively). Statistical analysis showed good agreements of cardiac output measurements at rest (R^2=0.83) and under stress conditions (R^2=0.74) using PC-MRI and PV loop techniques. Cardiac output measurement using cine MRI and PV loop techniques also showed good agreement at rest (R^2=0.85) and under stress conditions (R^2=0.76). Furthermore, Figure 2 shows cardiac outputs determined with the three modalities showed good agreements over a wide range of heart rates (90-180 bpm).

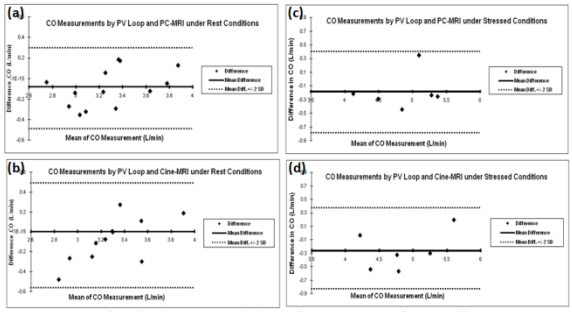

Figure 2. Bland-Altman analysis of agreement for cardiac output correlations of (a) PC-MRI vs. PV loops at rest, (b) cine MRI vs. PV loops at rest, (c) PC-MRI vs. PV loops under stress condition, (d) cine MRI vs. PV loops under stress condition.

CONCLUSIONS: This study showed good agreement between two MR techniques and invasive standard PV loop analysis for assessment of LV function. It demonstrates that MRI can provide a reliable, noninvasive measurement of cardiac output that can be carried out without the complications that are inherent with current invasive procedures.

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