Respiration-Resolved Ventricular Function Evaluation Using a 5D Cardiac MRI Technique

Holden H Wu[1,2], Dwight G Nishimura[2], Michael V McConnell[1,2], and Bob S Hu[2,3]

[1]*Cardiovascular Medicine, Stanford University, Stanford, CA, United States,* [2]*Electrical Engineering, Stanford University, Stanford, CA, United States,* [3]*Palo Alto Medical Foundation, Palo Alto, CA, United States*

Introduction: Conventional MRI methods for assessing cardiac function aim to suspend or counteract respiratory motion to avoid artifacts. However, in many disease states, *e.g.* pericardial constriction and heart failure with preserved ejection fraction (HFpEF) [1, 2], it is precisely variations in cardiac function associated with respiration-induced intra-thoracic pressure changes that can reflect the pathophysiology. In this work, we utilize our recently developed respiration-resolved 5D cardiac MRI technique [3] in combination with *controllable modulation* of intra-thoracic pressure to improve characterization of the pressure-volume relationship and provide a more comprehensive evaluation of ventricular function.

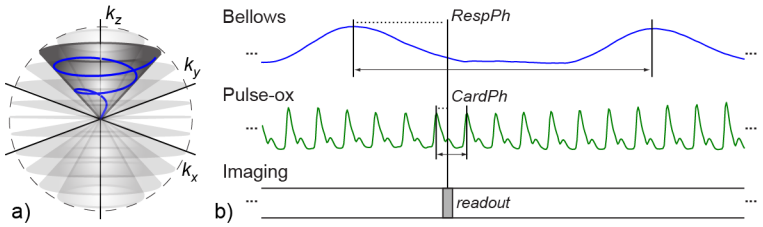

Fig. 1. (**a**) 3D cones trajectory. (**b**) The respiratory phase (*RespPh*) and cardiac phase (*CardPh*) of each readout are retrospectively determined from the recorded physiologic signals. Data are then re-ordered and reconstructed to obtain a 5D matrix.

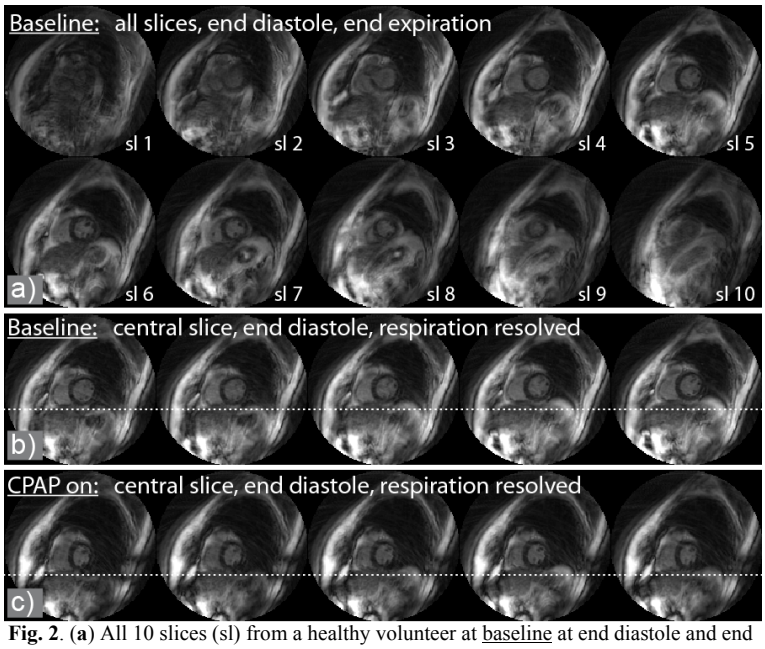

Fig. 2. (**a**) All 10 slices (sl) from a healthy volunteer at baseline at end diastole and end expiration (**b**) First 5 respiratory phases of the central slice in end diastole at baseline. (**c**) First 5 respiratory phases of the matching slice in end diastole with CPAP set to 15 cm-H_2O. The diaphragm is at a lower position due to increased intra-thoracic pressure and the volume of the left ventricle is reduced.

Methods: 5D Imaging: A 3D cones (Fig. 1a) SSFP sequence was used to acquire data during free breathing. The respiratory bellows and peripheral pulse oximeter were recorded during the scan (Fig. 1b) to facilitate retrospective re-ordering and reconstruction of acquired data as a 5D matrix (3D spatial, 1D cardiac phase, and 1D respiratory phase information) [3]. The respiratory and cardiac phases of each cone readout were retrospectively determined from the readout's relative temporal position within the local respiratory and cardiac cycles. The number of reconstructed cardiac and respiratory phases depended on the specific patterns during each individual scan.

Experiments: Scans were performed on a GE Signa 1.5 T Excite system using an 8-channel array. A short-axis volume with an FOV of 36x36x8 cm^3 and resolution of 2.4x2.4x8 mm^3 (150x150x10 matrix) was encoded using 340 cone readouts (*4-fold* acceleration vs. 3D Cartesian). After a baseline free-breathing scan, the subject was instructed to breathe through a mask connected to a continuous positive airway pressure (CPAP) device normally used for sleep apnea. Subsequent scans were then obtained during free-breathing with the CPAP device set to different pressure levels. Data oversampling covered a maximum respiratory cycle duration of 8 s to accommodate potential variations in the respiratory pattern. Scan time for one 5D dataset was *4 min 30 s*.

Results: Fig. 2 displays 5D data obtained from a healthy volunteer at baseline and with the CPAP set to 15 cm-H_2O. This 5D dataset can be reformatted as a "respiratory cine" at a fixed cardiac phase (Figs. 2b and 2c) to elucidate the effects of respiratory motion. As the CPAP increased intra-thoracic pressure, the diaphragm became biased to a lower position and its range of motion became constrained (Fig. 2c). A consistent reduction of ~20% in the left ventricular (LV) volume is noted throughout the respiratory phases.

Discussion and Conclusions: We have presented a novel respiration-resolved cardiac MRI technique for improving ventricular function assessment by using a rapid and robust 5D imaging strategy combined with controllable modulation of intra-thoracic pressure. Experimental results demonstrate the ability to measure a consistent change in cardiac volume under controlled intra-thoracic pressure changes in the physiologic range. Altering the preload is a very specific method of determining HFpEF [4], but volumetric measurements are difficult with ultrasound echocardiography and the Valsalva maneuver is difficult to quantify and reproduce. By using the CPAP device, we can modulate the intra-thoracic pressure in a reproducible manner (within and across subjects) to study the cardiac pressure-volume relationship over a considerable dynamic range. Quantitative measurements of ventricular volume with respect to pressure variations can be obtained from the 5D datasets. In disease states with an altered pressure-volume relationship, including HFpEF, our technique may provide important physiologic information for non-invasive diagnosis and monitoring.

References: [1] De Keulenaer GW, *et al.*, Circ 2011; 123: 1996-2005. [2] Borlaug BA, *et al.*, Circ 2011; 123: 2006-2014. [3] Wu HH, *et al.*, *Proc. 19th ISMRM*, p. 4359, 2011. [4] Hurrell DG, *et al.*, JACC 1997; 30: 459-467.