A systematic evaluation of left ventricular (LV) models for estimating LV volumes in children using cardiac cine (MRI)

Jiming Zhang1*, Carlo Uribe2, Jason Liu3, Benjamin Cheong2,4, Amol Pednekar4, Paolo Angelini2, Raja Muthupillai2,4

From 16th Annual SCMR Scientific Sessions
San Francisco, CA, USA. 31 January - 3 February 2013

Background
Assumptions about LV shape are often used to estimate LV volumes in ultrasound and x-ray angiography, which are not necessary for CMRI.

Purpose
Using CMRI as the gold standard, we sought to systematically evaluate the performance of commonly used models, and a linear combination of the models, to estimate LV volumes of children.

Methods
Subjects
198 children (137 male, age: 12.4 ± 1.2 years, range 11~15 years) who provided written informed consent, in the context of a screening study for causes of sudden cardiac death, were enrolled in this IRB approved study.

MRI Acquisition
Breath held CMRI cine images were acquired in standard orientations (4-chamber (4Ch), Left-Ventricular Outflow Tract (LVOT), and Short Axis (Sax)) were acquired using a vendor provided stock SSFP sequence at 1.5 T (Philips Healthcare) with an in-plane resolution < 2 x 2 mm², and an acquired temporal resolution < 50 ms for all subjects.

Data Analysis
An expert observer drew contours in end-diastole (ED) and in end-systole (ES) to estimate LV volumes on CMR images acquired in all orientations (Sax, LVOT, and 4Ch). In 4Ch and LVOT views, longitudinal length (distance from mitral valve annulus to apical endocardium), and the transverse width (at mitral valve annulus) of the LV were recorded.

Models
The performance of six geometric models (described in Figure 1), and 15 weighted models generated (LVV_w) using a linear combination of any two of the six geometric models (LVV_w = α_iLVV_i + β_jLVV_j, where α_i, β_j were the coefficients estimated in 100 subjects via minimizing the least-square’s error compared to volumes estimated from Sax) were evaluated.

Data Analysis
Using Sax volumes as the reference, percentage-error of EDV, ESV, and ejection fraction (EF) of all 21 models were calculated.

Results
Commonly used biplane[1] and triplane[1] ellipsoid models have significant mean percentage error (at least 9%) for EDV/ESV/EF (Table 1), and triplane model was more reproducible than bi-plane model. A linear-weighted model of biplane and parabolic models substantially diminishes percentage error for EDV, ESV and EF to 0.3±6.0%, 0.5±10.7% and 0.0±6.4% (α_{EDV} = 0.4, β_{EDV}=0.7; α_{ESV} = 0.9, β_{ESV}=0.2) respectively.

Conclusions
In this group of young children, our results show that the estimation of LV volumes of conventional bi-plane and triplane models can be significantly improved by using a linear weighted model of bi-plane and parabolic models. These findings have to be confirmed in a larger study.
Figure 1 Geometric models considered in the current study. A, L, and r: area, diameter and radius from short-axis slice at papillary muscle level; L: longer length from apex to base in 4CH and LVOT views; r1: bigger half width at mitral valve annulus in 4CH and LVOT views; h1: length from base to papillary muscle level; h2 = L-h1.

Table 1 Estimation result of EDV, ESV and EF by weighted models

| [%] | Biplane | Triplane | Parabola | Cone | Cutcone+Parabola | Cutcone+Cone |
|-----|---------|----------|----------|------|------------------|--------------|
| EDV | 10.4±9.8 | 0.3±6.0  | 0.3±6.0  | 0.3±6.0 | -0.7±7.0         | -1.0±7.4     |
| ESV | -10.8±160 | 0.5±11.0 | 0.5±10.7 | 0.5±10.7 | -0.7±7.0         | -1.3±11.8    |
| EF  | 13.3±8.6  | 0.0±0.5  | 0.0±0.5  | 0.0±0.5  | 0.1±6.7          | 0.2±7.3      |
| EDV | X        | -16.1±5.1| 0.3±6.0  | 0.3±6.0  | 0.0±6.1          | -0.1±6.1     |
| ESV | X        | -27.2±8.7| 0.5±10.7 | 0.5±10.7 | -0.4±10.4        | -0.6±10.8    |
| EF  | X        | 9.2±6.4  | 0.0±6.5  | 0.0±6.5  | 0.4±6.6          | 0.5±6.7      |
| EDV | X        | -140±66  | 0.7±7.7  | 0.2±7.6  | 0.2±7.6          | 0.2±7.6      |
| ESV | X        | -195±9.1 | 0.3±11.4 | -0.4±10.6| -0.5±10.8        |              |
| EF  | X        | 4±7.1    | 0.3±7.4  | 0.5±7.0  | 0.5±7.2          | 0.5±7.2      |
| EDV | X        | X        | X        | -43±4.3  | 0.2±7.6          | 0.2±7.6      |
| ESV | X        | X        | X        | -47±6.0  | -0.4±10.6        | -0.5±10.8    |
| EF  | X        | 4.4±7.1  | 0.5±7.0  | 0.0±8.8  | 0.0±8.8          | 0.0±8.8      |
| EDV | X        | X        | X        | X        | 14.0±11.2        | 0.0±8.8      |
| ESV | X        | X        | X        | X        | 15.3±13.4        | -0.1±10.3    |
| EF  | X        | X        | X        | X        | 0.9±7.9          | 0.1±6.9      |
| EDV | X        | X        | X        | X        | -1.6±11.1        |              |
| ESV | X        | X        | X        | X        | 0.3±13.5         | 0.3±13.5     |
| EF  | X        | X        | X        | X        | -1.6±9.3         | 0.0±9.3      |
Funding

The study was partly funded by Texas Heart Institute.

Author details
1Physics and Texas Center for Superconductivity, University of Houston, Houston, TX, USA. 2Center for coronary artery anomalies, Texas Heart Institute, Houston, TX, USA. 3Glenda Dawson High School, Pearland, TX, USA. 4Diagnostic and Interventional Radiology, St. Luke’s Episcopal Hospital, Houston, TX, USA.

Published: 30 January 2013

Reference
1. Thiele H, et al. JCMR 2002, 4(3):327-339.

doi:10.1186/1532-429X-15-S1-P234
Cite this article as: Zhang et al. A systematic evaluation of left ventricular (LV) models for estimating LV volumes in children using cardiac cine (MRI). Journal of Cardiovascular Magnetic Resonance 2013 15 (Suppl 1):P234.