**Methods:**

The echocardiographic images were obtained by the Philips IE33 imaging system with pulsed-and continuous-wave Doppler imaging and in conventional subcostal, apical, parasternal, and suprasternal planes. The MRI images were acquired from the Siemens 1.5-T Espree scanning system using TrueFISP™ sequence (a steady state sequence in which balanced gradients were used along all three axes). In addition, black blood imaging and flow study were performed with phase contrast imaging. The images were sent to an independent 3-D workstation for post processing by the physician for cardiac function evaluation. In this case, the findings included severe pulmonary insufficiency and the right ventricle end-diastolic volume was calculated to be 186 mL/M2 (increased) and the end-systolic volume was calculated to be 96 mL/M2 (increased).

The echocardiographic and MRI images were visualized and saved respectively as .AVI (audio video interleaved) and .JPG (joint photographic experts group) files. The echocardiographic images were stored in DICOM files after being exported from the imaging system (with 800x600 image matrix and 0.3x0.3 mm pixel spacing) and the MRI images were recorded in DICOM files (with 256x256 image matrix and 1.25x1.25mm pixel spacing). The most relevant planes for both echocardiographic and MRI images were then selected for the study.

Using MATLAB programming platform and image processing technology, a medical image fusion of echocardiogram and MRI (“E.MRI”) can be formed by the following sequence: 1) segmentation of the color Doppler flow signal; 2) registration (both location and cardiac cycle) of color Doppler and magnetic resonance images; and 3) fusion of both color Doppler and magnetic resonance images using geometric transformation.

**Segmentation**

Sequences of echocardiogram and MRI images were extracted from mp4 video clips and DICOM files, respectively, using software embedded with the source CDs. Both echocardiogram and MRI images were saved in 24 bit bitmap format. The segmentation of the color Doppler flow signal is based on pixel characterization of the RGB color format. The set of color samples from the Doppler color scale is established with a mean color of the Doppler image. This process involves selection of RGB pixels that fall in the specified range for the study.

A Euclidean distance comparison is used as a measurement for segmentation with “c” being the average color of the RBG column vector and “a” as an arbitrary point in the RBG domain (with “t” as threshold” and “R”, “G”, and “B” as RBG components of “a” and “c”):

D(a,c) = ||a – c||

= [(a-c)t

(a-c)]1/2

= [(aR-cR)2 + (aG-cG) 2 + (aB-cB) 2]1/2

Points within and outside the sphere defined as radius “t” are coded differently and the segmented image is formed. The color Doppler area is divided into the red and blue areas (green is not available in Philips IE33 system). Regions of blood flow that contained velocities above the defined range were not included in the segmentation process.

**Registration**

Both space and time registrations are needed for this study as both echocardiography and MRI are performed during cardiac motion. First, two-dimensional MRI and their corresponding echocardiographic images were selected. Second, time registration is needed for timing with the cardiac cycle. Lastly, three dimensional registration is needed for echocardiography due to its motion. Geometric image transformation with affine transform (a class of linear two-dimensional geometric transformation that maps variables such as pixel intensity into new variables by applying translation, rotation, scaling and shearing) is used for the final merging of echocardiography and MRI images.

The first stage of the registration is size reconciliation. This is followed by planar or rotational orientation with rotation of the MRI image to match the color Doppler flow image. The final step is image transfer with the anatomic fiducial markers (semilunar and atrioventricular valve junctions). Time registration is accomplished via the surface electrocardiogram and the location of the peak of the QRS R wave.

**Fusion**

Fusion was performed with the MATLAB program after importing the echocardiography

(with RGB images) and MRI (with grey level images) DICOM files and setting internal fiducial markers for anatomic landmarks (atrioventricular and semilunar valve annular junctions) in these RGB and grey level images (5). In order to “fuse” the grey level with the RGB images, the two-dimensional matrix is extended into the three-dimensional matrix.

 In other words, the MRI pixels needed to be replaced by the color Doppler pixels with adjustment of the RGB matrix format and pixel character. The fused image is saved in the .AVI format in the 24-bit bitmap format where red and blue layers are taken from color echocardiography images and green layer is taken from grey level MRI images.

**MatLab Code**

A custom Matlab code was developed for echocardiogram and MRI image registration. The code consists of main function (MRI\_US\_Registration gui) and two sub functions (getImages and ImCombMRIUS). Sub function getImages reads a sequence of image files. Main function creates user Interface with registration and visualization controls and displays images and passes registration information (scaling factor, angle of rotation, and planar shift values) to sub function ImCombMRIUS. Sub function getImages reads a sequence of image files. In addition, sub function ImCombMRIUS performs image registration by scaling, rotating and shifting US image respectively to MRI image in accordance with registration information supplied via user Interface.

Upon launching MRI\_US\_Registration\_gui, two menus appear to request the user to select sequence of MRI and US images. Then, the user interface appears displaying two overlaying MRI and US images. Both images are first from the respective sequences. The sliding bar controls allow the user to shift left and right, rotate and scale US image relative to the MRI image performing 2D size reconciliation and planar or rotational orientation. The radio buttons MRI, Echo, and MRI&ECHO indicate what image sequence can be browsed through. Browsing through MRI image set while keeping US image stationary allows to select MRI imaging plain most closely corresponding to the given echocardiography image and perform 3D space registration. Browsing through echocardiography image set performs time registration. If MRI&Echo button is selected, user will browse through both stacks simultaneously. Additional control allows the user to adjust intensity of MRI image for visualization improvement.