Videodensitometric Measurement of Absolute Left Ventricular Volume Using Dual-Energy Digital Subtraction Angiography

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While videodensitometric analysis of digital subtraction angiography (DSA) images has the potential to measure absolute cardiac volumes without recourse to geometric models, application of the technique has been generally limited to the measurement of relative volumes (e.g. ejection fraction). This dissertation studied the ability to measure absolute left ventricular (LV) volume in patients using videodensitometry.

Imaging was performed with dual-energy DSA in order to eliminate errors stemming from patient motion artifacts. Ideally, the iodine signal in a DSA image is given by $S_i = ((\mu_i)^{DE}) * \rho_i * t_i$. To determine LV volume we need to determine t_i, the iodine thickness, for each pixel within the ventricle. The patient-specific dual-energy iodine attenuation coefficient $((\mu_i)^{DE})$ was measured with a contrast-media-filled phantom. The time-varying blood iodine concentration ($\rho_i(t)$) was measured using a continuous withdrawal of blood from the aortic root (pulmonary artery injection assured good mixing). Scatter correction of the image data was performed by fitting a two-dimensional spline surface to scatter values measured with a grid of small Pb occluders. Two injections were performed in each of 8 patients, one at rest and one during increased cardiac output due to the administration of the positive inotropic agent dobutamine ($n = 16$). Videodensitometric volumes were determined at end-diastole and end-systole.

The technique for the measurement of blood iodine concentration uses a catheter to draw blood from the LV through a detection cell. This occurs as the iodine bolus passes through the heart. The cell determines iodine concentration by measuring x-ray attenuation as the iodinated blood passes between a low power x-ray tube and a diode detector. In vitro and in vivo testing of the system was conducted to evaluate its accuracy and to investigate the ability to measure cardiac output from the time-concentration curve via the indicator-dilution method. Cardiac output measurement by this method in an animal model (CO_I) agreed closely with cardiac output measured simultaneously with an aortic flow probe (CO_P), namely $CO_I = 1.02 * CO_P - 0.03$ L/min, with $r = 0.95$, SEE = 10% and $p < 0.001$.

The dual-energy densitometric algorithm was first tested with 8 iodine filled balloons (range 10 to 250 ml) placed inside a chest phantom. The videodensitometric volumes (V_{VDM}) were related to the true volumes (V_T) by: $V_{VDM} = 1.03 V_T + 4$ ml, with $r = 0.99$, SEE = 8 ml. To validate the volumes measured in patients, cardiac output (CO) was calculated from the densitometrically determined end-diastolic volume (EDV) and end-systolic volume (ESV) ($CO_{VDM} = (EDV - ESV) \times$ Heart Rate) and compared with the cardiac output determined from the simultaneous iodine concentration measurement $\rho_i(t)$ using the indicator-dilution method. Videodensitometrically measured cardiac output (CO_{VDM}) compared with indicator-dilution cardiac output (CO_{ID}) according to the regression relationship: $CO_{VDM} = 1.09 CO_{ID} - 0.3$ L/min, $r = 0.95$, SEE= 1.3 L/min. Videodensitometrically measured stroke volume (SV_{VDM}) compared with indicator-dilution stroke volume (SV_{ID}) according to the regression relationship: $SV_{VDM} = 0.92 SV_{ID} - 11$ ml, r=

0.85, SEE = 13 ml. In conclusion, absolute cardiac volumes can be accurately measured from DSA images when proper signal calibration and scatter correction procedures are performed.