CARDIAC AND RESPIRATORY GATING FOR A SMALL ANIMAL CT/SPECT SYSTEM

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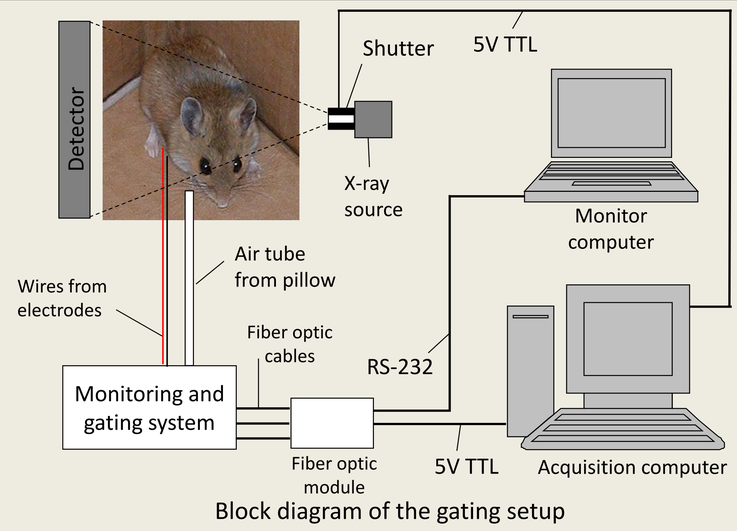
MOTIVATION FOR GATING

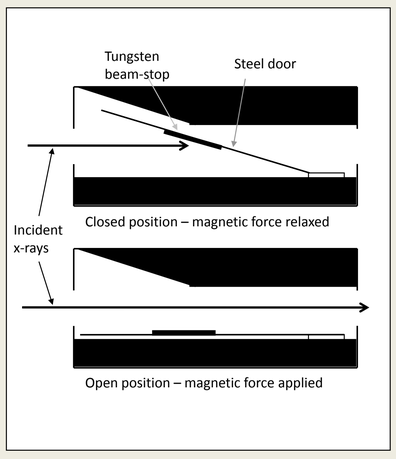
- Murine heart rate up to 600 bpm
- The heart wall velocity of a healthy mouse heart at end diastole is approximately 0.4 cm/s and about 1.7 cm/s during systole
- Respiratory movement further complicates high resolution cardiac imaging

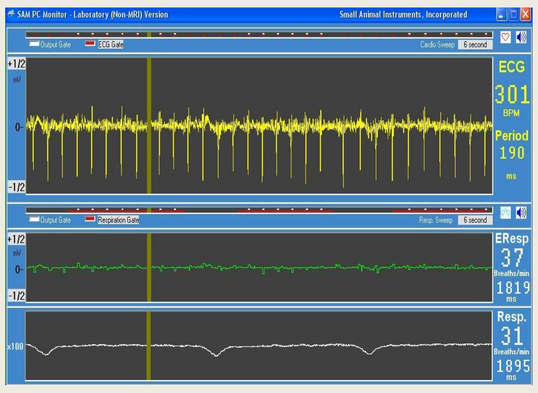
CARDIAC CT GATING



Block diagram of the gating setup

- The high speed x-ray shutter (model LS055-X2W, NMLaser) is designed to block the majority of x-rays emitted from a continuously operated microfocus x-ray source (SourceBlock SB-80-1k, SourceRay)
- Limited field of view of the shutter (3 cm x 3 cm) sufficient to image the heart
- The shutter allows for fast functional CT imaging of the heart at high resolution which is usually not possible with this modality

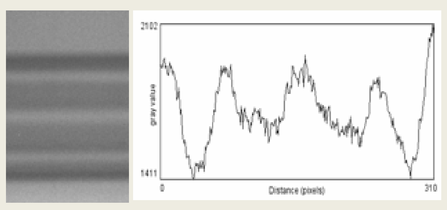




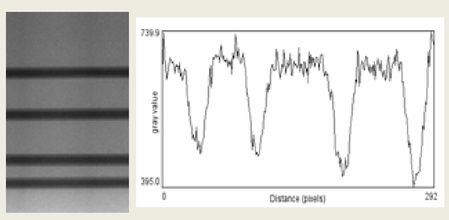
- Short exposures are initiated at a preset time interval following the TRS wave in the ECG signal during expiration (SAM-PC, model model 1025L, SAI).

SHUTTER PERFORMANCE TESTS

- Four glass capillaries, 0.7 mm diameter positioned 8 mm from axis of a cylindrical piece of Teflon. The phantom was mounted to the axis of a servo motor.
- A motor rotation speed setting of 2 revolutions per second results in a capillary transverse velocity of 10 cm/s, which is a factor of 5 times faster than the wall speed during systole.
- Single shot images of the moving capillaries were taken with varying shutter open/close times. Capillary profiles can be seen below.



80 ms pulse time



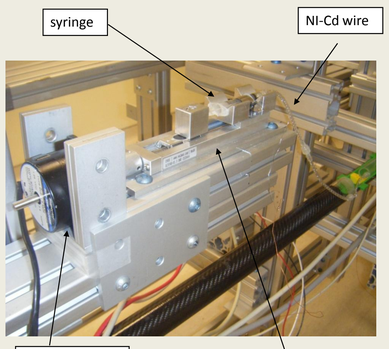
20 ms pulse time

	Stationary	80 ms	20 ms
Capillary 1	22.3	35.3	24.7
Capillary 2	21.6	56.4	21.3
Capillary 3	21.3	59.6	22.8
Capillary 4	21.3	29.9	24.0
AVG	**21.6**	**45.3**	**23.2**

FWHM of capillaries, all values given in pixels

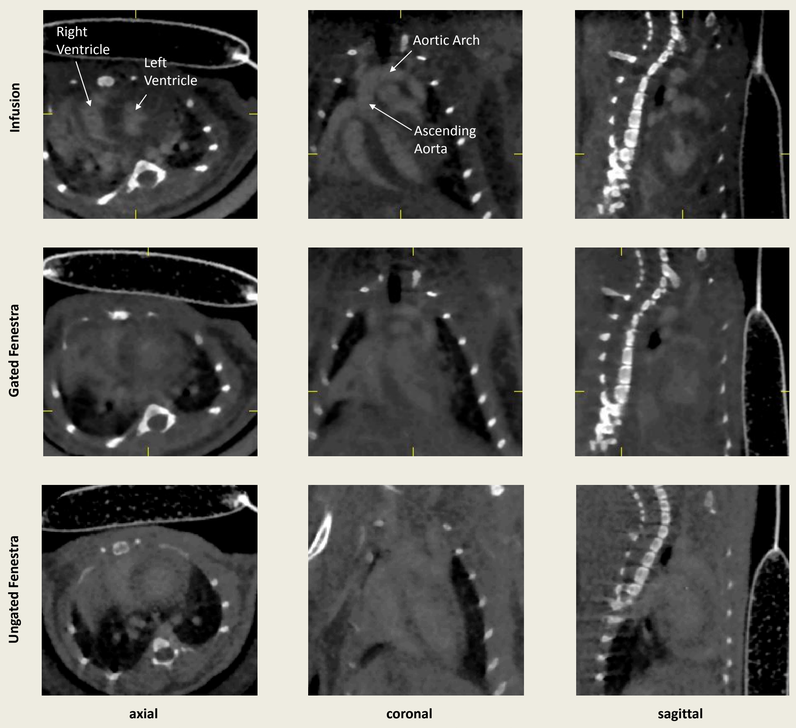
INFUSION SYSTEM

- Home-built infusion system for controlled delivery of contrast agent during the entire CT scan
- Syringe mounted on a motorized computer controlled translation stage (VELMEX Series A15)
- Contrast exiting the syringe flows through an extension tube to a butterfly needle inserted into tail vein
- The syringe is heated by a Ni-Cd wire to match body temperature of mouse (37 C) and maintain viscosity of the iodine based contrast agent



EXAMPLE CARDIAC CT SCANS

- Cardiac CT scans performed using a) the slow infusion system and Omnipaque 300 with gating and b) a bolus injection of Fenestra VC (ART Inc. Montreal, Canada) both with and without gating.
- The total amount of contrast agent injected was approximately 0.3 ml in all cases.
- Premise: Achieving same or better contrast by using the slow infusion system and Omnipaque versus the much more expensive Fenestra would make long-term studies on small animals better in terms of image quality as well as much more cost effective
- In gated scans shutter open time was 20 ms.
- In order to compare the contrast in the scans, regions of interest were drawn in the blood pools of the left and right ventricles and in the surrounding muscle tissue in the chamber walls.



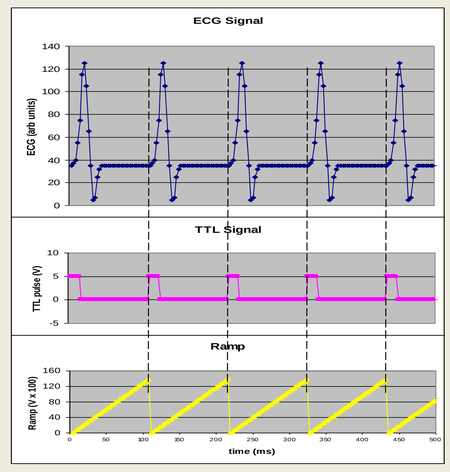
Contrast enhanced CT images using: the infusion system with cardiac and respiratory gating (top row); Fenestra with cardiac and respiratory gating (middle row) ; and Fenestra with no gating (bottom row).

	Right ventricle	Left ventricle	Muscle	Chamber-muscle contrast
Infusion system with gating	886.6	881.6	151.4	**4.84**
Gated Fenestra	544.4	539.1	145.6	**2.72**
Ungated Fenestra	489.7	479.2	164.1	**1.95**

Signal data given in Hounsfield units

SPECT SUBSYSTEM AND CARDIAC SPECT

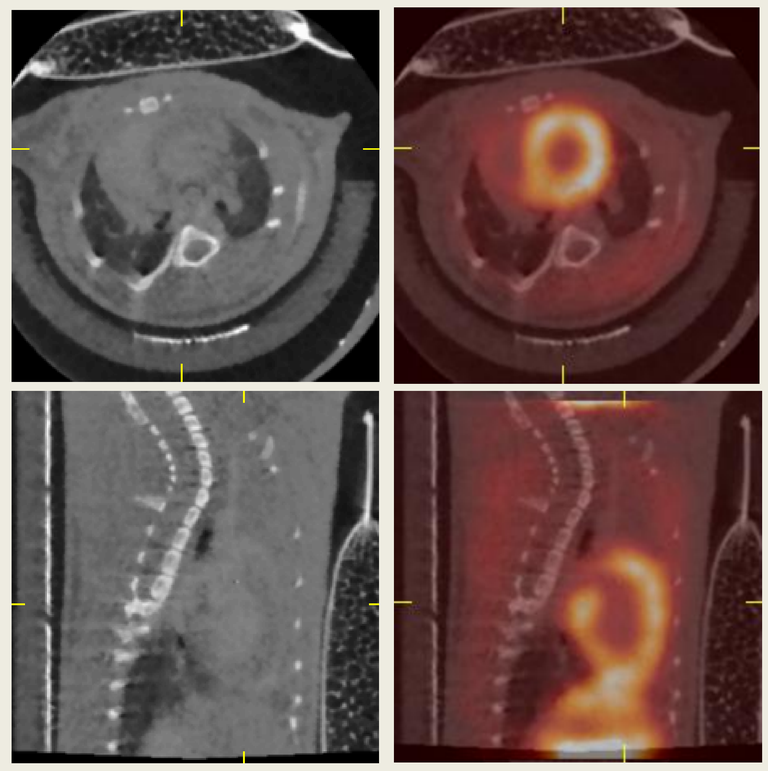
- SPECT system includes up to four gamma cameras (RayVisions, Inc., Yorktown, VA), each with 2x2 array of Hamamatsu H8500 PSPMTs and 1.5 mm pitch NaI(Tl) crystal array (10 cm x 10 cm FOV)
- SPECT camera electronics generate a linearly increasing ramp voltage signal for list mode acquisition and event time stamping. Voltage resets to zero each cardiac cycle.
- For each gamma ray event, the deposited energy, the ID of the event detector, the x- and y-position of the NaI(Tl) crystal of the detector, the SPECT projection number, and the ramp voltage are recorded.
- List mode data are used to form projection images binned in time per user preference.
- Image data fused with CT



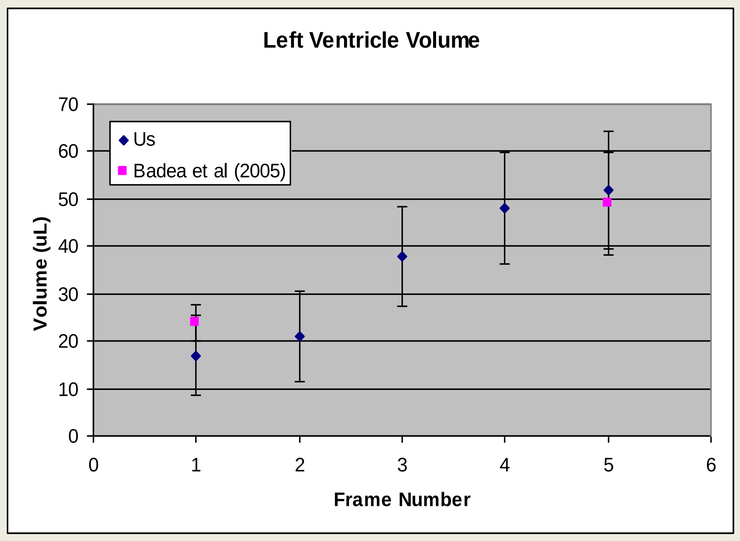
- Plots of the ECG, respiratory, and ramp voltage signals with respect to time. The dashed lines on the beginning of the rising edges of the ECG signal indicate when the ramp voltage is reset.

EXAMPLE GATED CARDIAC CT/SPECT SCAN

- Cardiac SPECT setup:
  - 4 detectors, 180 degree scan, 3 degree increments (1 hr total scan time)
  - 0.5 mm pinholes, full-cone setup, 20 mm pinhole to AOR
  - 0.2 ml Tc-99m-sestamibi injected into tail vein (10.8 mCi)
  - gated on systolic portion of heart beat during expiration
  - cardiac cycle divided into 5 equal length phases



Cardiac gated CT/SPECT axial and sagittal slices of a mouse injected with Tc-99m sestamibi



Plot of the volume of the left ventricle in µl, measured from the reconstructed CT volume, over five phases in the cardiac cycle. End-systolic and end-diastolic volumes are compared with those measured by Badea et al. *Molecular Imaging* **4(2)** 110-116

CONCLUSIONS

- Prospective acquisition of high contrast murine cardiac CT images with high temporal and spatial resolution is possible using a custom x-ray shutter and continuous iodine contrast infusion.
- The x-ray shutter and contrast infusion systems described here were designed as compact and relatively inexpensive additions to a SPECT-CT scanner to improve the visibility of cardiovascular structures in the free-breathing, anesthetized animal.
- The system permits the use of traditional inexpensive iodine-based CT contrast agents thus making it potentially attractive for high volume cardiac imaging applications.
- The gated slow infusion images permit high wall-blood pool contrast and clear visualization of left and right ventricles and the ascending and descending aorta.

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