# A Practical Scanner for Small Animal Photoacoustic Computed Tomography Imaging

Timothy Morgan[1], Robert Kruger[2], Richard Lam[2], Daniel Reinecke[2], Patrick Del Rio[2], Paul Picot[1], and Michael Thornton[1]
1. Endra, Inc., Boston, MA, USA 2. OptoSonics, Inc., Oriental, NC, USA

## Introduction

Photoacoustic computed tomography (CT) imaging of small animals can achieve nano-molar sensitivity at depth (> 20 mm) with spatial resolution greatly exceeding that of purely optical techniques.

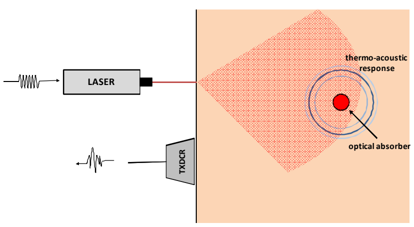
Early designs of photoacoustic instruments often focused on the technology innovation rather than usability which has limited the use of photoacoustic imaging by non-imaging experts.

Goals: Design a photoacoustic CT scanner for routine use in small animal laboratory imaging applications, optimizing for:

1. performance
   - contrast sensitivity
   - field of view
   - spatial resolution
   - complexity
2. workflow
   - animal handling
   - throughput
   - ease of use

## Introduction to Photoacoustics

Photoacoustic imaging is a technique that combines optical illumination, optical absorption, and ultrasound detection to map the location of absorbers within light scattering media with high sensitivity and spatial resolution. A short pulse of electromagnetic radiation induces a milli-Kelvin rise in temperature within the absorber resulting in a thermal expansion. The rapid heating and cooling results in an acoustic wave that is emitted from the absorber that may be detected at the tissue surface by acoustic receivers. The depth of the absorber may be determined by the time of arrival of the thermo-acoustic signal at the tissue surface.




A typical photoacoustic imaging system employs a laser source that generates pulses of light <10 nsec in duration with a pulse energy in the 1-30 mJ range. Acoustic receivers are typically wideband and have center frequencies in the 1-20 MHz range.

## Photoacoustic CT Scanner Design

### Scanner Components

A photoacoustic CT scanner has been designed specifically for in vivo preclinical imaging applications. A prototype unit has been built and characterized. The system is in routine use in cancer biology applications.


(left) acquisition/reconstruction console, (middle) scanner cabinet, and (right) diagram illustrating light delivery, animal tray, and detector position

**Digital Acquisition System**
- 128 channels (no multiplexing)
- 40 MHz
- On-board view averaging

**Tunable, Near Infrared Laser**
- Nd:YAG laser pumped OPO
- 7 ns pulses, 25 mJ per pulse
- Tunable wavelength: 690-980 nm

**128-Element Detector**
- Unfocused transducers
- 5 MHz, 3 mm diameter

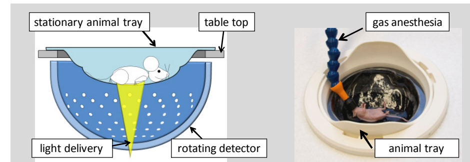
**Cabinet**
- Small footprint
- 36” working height

**Scanner Operation**
- Graphical user interface
- Computer controlled, protocol driven acquisitions
- Automatic laser tuning, laser firing, detector rotation, detector read-out, and laser output measurements

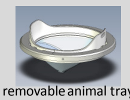
## Scanner Workflow

### Animal Handling

The system was designed to minimize animal preparation and positioning time. We have eliminated the need for submerging the animal or tissue specimen, as has been reported with other photoacoustic imaging systems.




(left) illustration and (right) photograph of mouse positioned for scanning



removable animal tray locks into position

- Prone or supine animal position
- Head remains above water
- Simplified anesthesia tube management
- Access to tail for catheterizations

### Throughput

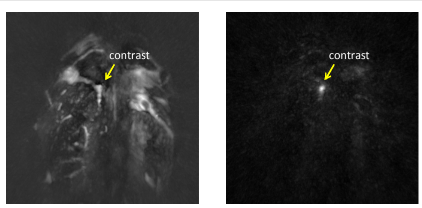
Standard scanning protocols used for quantitative studies are:

| | |
|---|---|
| • 1 wavelength, 60 views, 8 pulses/view | 90 sec |
| • Hb concentration study (2 wavelengths) | < 200 sec |
| • Quantitative probe concentration (5 wavelengths) | < 10 min |

## Example Images

### Dual Wavelength with ICG

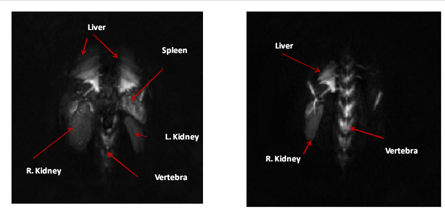
Images of an intact mouse injected with 5 µL of 3 µM ICG in back of mouse were acquired at two wavelengths (805 and 835 nm) and then subtracted. Images were acquired at 60 rotational positions of the transducer array with the thermo-acoustic signal from 8 pulses of light averaged at each view.




(left) The raw reconstructed photoacoustic data acquired at 805 nm. (right) The resulting subtracted image (image at 805 nm – image at 835 nm)

### Single Wavelength – No Added Contrast

Mouse images were acquired with no added contrast at 750 nm, 90 rotational positions of the transducer array, and 4 pulses of light averaged at each view.



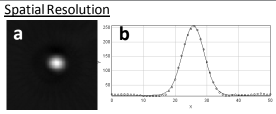

Photoacoustic data were reconstructed with 0.1 mm voxels and displayed as a maximum intensity projection for a 1.9 mm coronal slab of volume data. Abdominal organs are easily delineated along with larger bone structures with only endogenous contrast.

## Photoacoustic CT Scanner Technical Specifications

| | |
|---|---|
| Spatial Resolution | < 280 µm |
| Contrast Sensitivity | < 350 nM (ICG) |
| Field of View | > 20 mm |

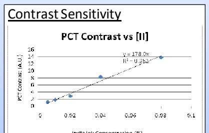
Kruger *et al., Proc. SPIE BIOS,* Vol. 7177, 2009

### Spatial Resolution



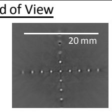

The spatial resolution of the scanner was determined using a 200 µm absorbing point target (a). The associated point spread function is represented by a profile plot through the test target (b).

### Contrast Sensitivity




Successive dilutions of an absorbing dye (India ink) were imaged in order to determine the contrast sensitivity.

### Field of View




Photoacoustic images of an array of 400-µm dots on 2.5-mm centers reconstructed in the transverse plane at the center of the field of view.

## Summary

- A photoacoustic CT imaging system for small animals was designed, built, and tested with advanced capabilities in resolution and sensitivity at depth.
- Minimal animal preparation, fast scan speeds, and an easy to use interface result in high throughput.
- The imaging system is used routinely in research laboratory small animal studies.

**Endra, Inc.**
222 Berkeley Street, Suite 1040, Boston, MA 02116 and
35 Research Drive, Suite 100, Ann Arbor, MI 48103
e:tmorgan@endrainc.com
p: (734) 274-2258