A Portable Time-Gated Fluorescence Imaging System for Quantitative Perfusion Assessment During Open Orthopedic Surgeries

Yue Tang,[1] Petr Bruza,[1] Jonathan T. Elliott,[2] Joseph S. Sottosanti,[2] Jeffrey D. Renk,[1] Chelsey L. Recendez,[2] Eric R. Henderson,[2] Ida Leah Gitajn,[2] and Shudong Jiang[1]

[1]Dartmouth College, Thayer school of Engineering; [2]Dartmouth-Hitchcock Medical Center, Department of Orthopaedics

2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

ABSTRACT

Purpose

- Accurate intraoperative perfusion assessment is critical for guiding debridement in orthopedic injuries
- Existing fluorescence systems are unsuitable for **resource-limited** or **high-ambient-light** environments
- **Goal:** Develop a compact, portable Indocynine green (ICG) fluorescence imaging system for quantitative perfusion assessment in austere surgical setting.

Method

- **Time-gated acquisition** synchronized with **pulsed NIR LED excitation** to suppress ambient light
- **Curved LED array** for uniform excitation across a large rectangle field of view
- Evaluated via simulations and phantom studies
- Benchmarked against a commercial system: excitation uniformity, sensitivity, dynamic range, noise floor, spatial resolution, weight
- *In vivo* validation in a rat model (skin-on, skin-off, and fractured bone) after IV ICG.

Result

- **87% lighter** than commercial system
- Curved LED array improved excitation homogeneity: area with ≥70% peak intensity doubled
- Phantom studies: higher ICG sensitivity and **broader dynamic range** under high ambient light
- *In vivo*: improved bone-soft tissue contrast, reduced noise, clearer dynamic perfusion patterns

Conclusion

- Delivers quantitative perfusion imaging **comparable to or exceeding** commercial systems
- Greatly enhanced **portability** and **ambient-light resistance**
- Strong potential for **field hospitals, disaster response,** and resource-constrained surgical settings

CONTACT

Petr Bruza
Dartmouth College
15 Thayer Drive, Hanover, New Hampshire
Petr.Bruza@dartmouth.edu

INTRODUCTION

- High-energy trauma (gunshot, blast, vehicular) produces complex tissue damage with variable vascular compromise. Regions that lose perfusion become **nonviable**, impeding healing and serving as a nidus for infection and inflammation.
- Surgical debridement requires balancing removal of dead tissue vs. preservation of functional tissue. Over-excision compromises **structural integrity** and reconstructive options.
- Conventional **visual assessment is subjective** and poorly related to true viability.
- Indocynine green (ICG)-based Dynamic Contrast-Enhanced Fluorescence Imaging (DCE-FI) offers **objective, real-time, quantitative** perfusion data to guide more precise debridement decisions.
- However, commercial fluorescence systems are **bulky**, depend on stable power, and poorly handle ambient light, impractical for forward surgical teams in combat zones or disaster response.
- To address this, we developed a compact Tissue Perfusion Imaging system (**cTPI**) using a **battery-powered**, **time-gated** design that syncs ICG excitation with camera shutter, eliminating ambient light interference for reliable imaging.

METHODS

- **Imaging system (cTPI):** time-gated fluorescence camera with a high-sensitivity, multi-pulse-integrating sensor, custom lens, and narrow bandpass emission filter to reject excitation leakage; a white-light camera for RGB imaging.
- **Illumination:** custom designed wide rectangle field LED source system, including two symmetric LED arrays (each 2×5 high-power 780 nm NIR LEDs) deliver ~100 ns pulses at 5% duty cycle, with aluminum housings for heat dissipation.
- **Power & portability:** lithium-ion battery pack with voltage regulation; a laser distance meter maintains a standardized 30 cm working distance; imaging head weighs 0.5 kg (handheld-capable, typically lamp-arm mounted).

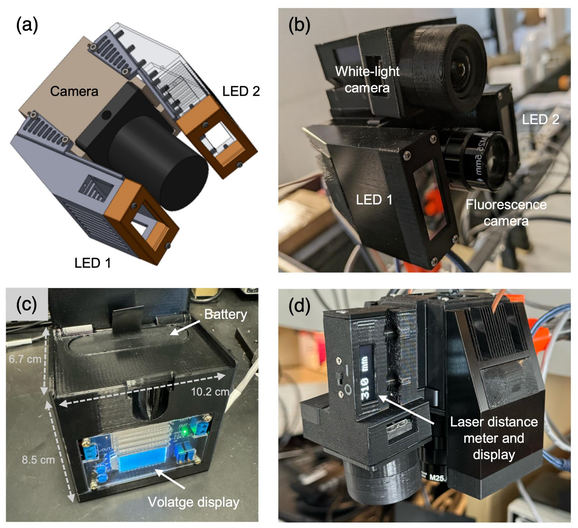

Figure 1. Compact Tissue Perfusion Imaging system (cTPI): (a) 3D layout of the camera and LED housings; (b) photo; (c) portable battery box; (d) laser distance meter and its reading display.

METHODS

- **Phantom studies:** ICG-equivalent phantom imaged by both cTPI system and commercial SPY-PHI system, under low and high ambient light, to compare imaging performance, including sensitivity, dynamic range, noise and spatial resolution (by a USAF 1951 target).
- **In vivo small animal studies:** four rat hindlimb model imaged sequentially with both systems for 10 min after IV ICG (0.1 mg/kg), across intact-skin, exposed-tibia, and fractured bone. Average time-intensity curves were derived from regions of interest.
- **Preliminary patient imaging:** Patients undergoing orthopedic surgery have been imaged intraoperatively, demonstrating that cTPI can be readily integrated into the clinical workflow.

RESULTS

- **Phantom studies:** The imaging performance of the cTPI system is comparable or superior to that of the commercial SPY-PHI fluorescence imaging system.
- cTPI system: **87% lighter total weight**, **4× better ICG sensitivity**, and a **10× wider dynamic range** under high ambient light.

Table 1. Imaging performance comparison: SPY-PHI vs. cTPI

Imaging characteristics		SPY-PHI	cTPI
FOV at 30 cm		26.9 x 13.6 cm	15.5 x 12.0 cm
Pixel bit depth		8-bit	12-bit
Frame rate (frame per second)		30 fps	18 fps
Spatial resolution (lp/mm)		2.83	3.56
Minimal detectible ICG		12 nM	3 nM
Dynamic Range	High Ambient	1:100	1:1000
	Low Ambient	1:80	1:50
Noise Floor	High Ambient	24%	18%
	Low Ambient	19%	12%
Weight	Imaging Head	1 lb.	1.1 lb.
	Total with peripherals	45.3 lbs.	5.9 lbs.

- **in vivo contrast:** cTPI showed clearer separation between hypo-perfused bone and surrounding soft tissue during ICG wash-in.

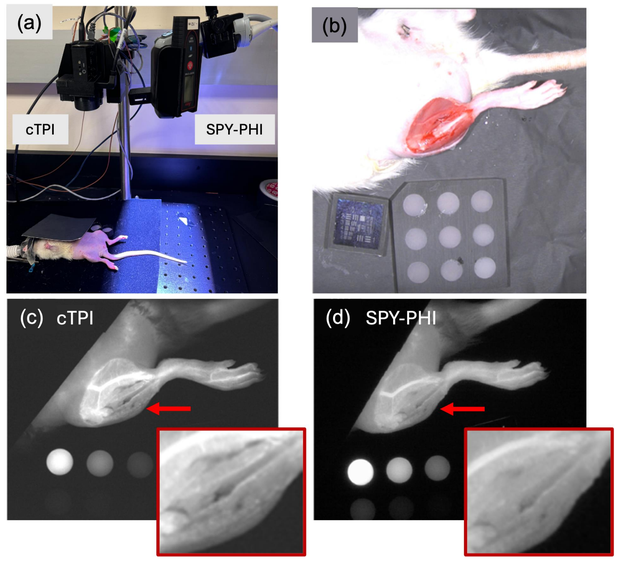

Figure 2. In vivo animal study: (a) Experiment set-up; (b) White-light reference image of rat hindlimb following surgical exposure of femur next to ICG-equivalent phantoms; (c) Fluorescence image captured by cTPI system at t = 1 min; (d) Corresponding fluorescence image captured by SPY-PHI system.

RESULTS

- **Enhanced dynamic kinetics:** Both systems showed substantially lower fluorescence intensity in broken bone compared to soft tissue, with a **greater signal separation** captured by cTPI system.

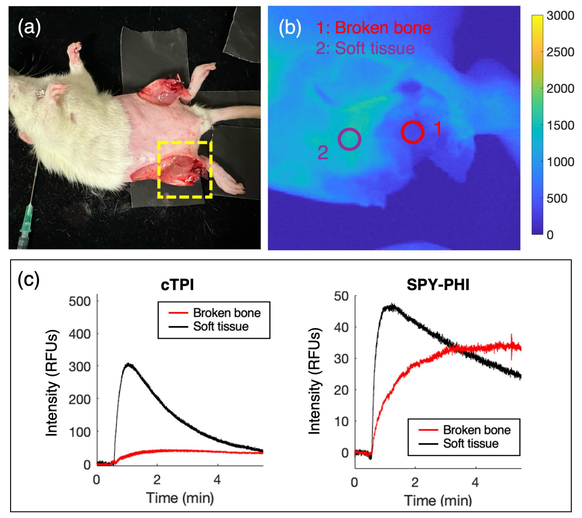

Figure 3. In vivo animal study: (a) White-light image of an anesthetized rat with tibiae exposed and fractured on both legs; (b) ROIs overlaid on fluorescence image; (c) Dynamic fluorescence intensity curves averaged from the ROIs in (b), with broken bone signals depicted in red and soft tissue signals in black, recorded by both cTPI and SPY-PHI systems.

CONCLUSIONS

- cTPI system extends **quantitative perfusion assessment** to resource-constrained surgical settings through a compact, portable, battery-driven design with time-gated acquisition to eliminate ambient light interference.
- cTPI system combines exceptional portability (**87% lighter**) with superior sensitivity (**3 nM vs. 12 nM**) and a far broader dynamic range under high ambient light (**1:1000 vs. 1:100**).
- Both phantom and in vivo small-animal validation studies confirmed cTPI imaging performance **comparable to or exceeding** commercial systems, overcoming key barriers to fluorescence-guided surgery in austere environments.
- Enables objective perfusion-guided debridement for **combat casualty care, disaster response,** and other challenging scenarios with potential to improve patient outcomes.
- **Future work:** Further improve excitation uniformity, expand the imaging field of view, and develop a streamlined user interface to provide real-time guidance for surgical decision-making.

REFERENCES

- Murray CK, Hsu JR, Solomkin JS, et al. Prevention and management of infections associated with combat-related extremity injuries. *J Trauma.* 2008;64(3):S239-S251.
- Bosse MJ, MacKenzie EJ, Kellam JF, et al. An analysis of outcomes of reconstruction or amputation of leg-threatening injuries. *New Engl J Med.* 2002;347(24):1924-1931.
- Sevick-Muraca EM. Translation of near-infrared fluorescence imaging technologies: emerging clinical applications [published online ahead of print 20111027]. *Annu Rev Med.* 2012;63:217-231.
- Pacher P, Nagayama T, Mukhopadhyay P, Bátkai S, Kass DA. Measurement of cardiac function using pressure-volume conductance catheter technique in mice and rats. *Nat Protoc.* 2008;3(9):1422-1434.