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Considerations for NIR-I and short-wave infrared (SWIR) fluorescence imaging within a clinical operating room.

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Abstract

Short-wave infrared (SWIR/NIR-II) fluorescence imaging has received increased attention for use in fluorescence-guided surgery (FGS) due to the potential for higher resolution imaging of subsurface structures and reduced autofluorescence compared to conventional NIR-I imaging. As with any fluorescence imaging modality introduced in the operating room, an appropriate accounting of contaminating background signal from other light sources in the operating room is an important step. Herein, we report the background signals in the SWIR and NIR-I emitted from commonly-used equipment in the OR, such as ambient and operating lights, LCD screens and surgical guidance systems. These results can guide implementation of protocols to reduce background signal.

Keywords

SWIR; NIR II window; medical imaging; fluorescence guided surgery

1. INTRODUCTION

In the past 5 years, SWIR fluorescence imaging has gained attention within the FGS community as an imaging modality with the potential to provide higher spatial resolution of subsurface features¹⁻⁴. As these translational efforts progress⁵⁻⁸, it is important to understand the sources of background signal in the surgical environment. To that end, we report on our initial experiences measuring potential sources of ambient contamination in SWIR and NIR-I channels originating within a modern operating room (OR). By isolating NIR-I and SWIR-generating sources, we quantify and compare the contributing intensity measured from each separate source of background signal, both through direct viewing as well as in an operating configuration.

2. METHODS AND MATERIALS

2.1 A modified clinical SWIR imaging system

The SWIR imaging system is shown in Fig. 1 and consists of a NIRvana 640 InGaAs camera (Princeton Instruments, Trenton, NJ) with an 1100 nm long pass dichroic filter mounted to a modified Zeiss S1 surgical microscope stand (Carl Zeiss AG, Oberkochen, Germany). Illumination was provided by a 760 nm laser (CrystalLaser, Renova, NV, USA) expanded to accommodate the surgical field with a power density of 28 mW/cm². SWIR images were acquired using an exposure time of 150 ms. The imaging system was also configured to

include an NIR-I channel along the same optical path. Specifically, a 950 nm dichroic mirror included in the optical path reflected NIR-I emission through an 800 nm dichroic long pass towards a PCO Edge 4.2 sCMOS image detector (PCO Inc., Kelheim, Germany). This modification permitted imaging SWIR and NIR-I fluorescence through the same optical path in rapid sequence. Exposures times for the NIR-I channel were 100 ms. Image processing involved dark image subtraction for both SWIR and NIR-I channels.

2.2 Operating room experiments

We surveyed a modern OR and identified the sources of background NIR-I and SWIR:

1) Stryker Berchtold LED F Generation surgical lights, 2) industrial LED ceiling lights, 3) NEC model V462 LCD wall monitor, and 4) a Medtronic StealthStation S8 Navigation System which includes an infrared tracking system and Navigation LCD monitor. Each of these systems were isolated and imaged directly by the NIR-I/SWIR imaging system.

To evaluate each signal-emitting background source's effect on imaging under realistic conditions, an imaging target was placed on top of the central surgical bed with the imaging system positioned directly over the surgical bed at a working distance of 10 cm. The imaging target was a Spectralon® Diffuse reflective standard (Labsphere, NH, USA) with 99% reflectance as used to measure incidental SWIR and NIR-I signal within the imaging plane. To quantify the additional signal incident upon the reflectance standard, average intensity (cps) was calculated from a selected region of interest inside the reflectance standard for each isolated background source in both the NIR-I and SWIR channels. (See Fig. 3). By plotting the average intensity (cps) measured from the reflectance standard, an absolute comparison of signal contribution can be made across both NIR-I and SWIR channels in all signal-emitting sources within the OR room.

3. RESULTS

Figure 2 illustrates the resulting fluorescence images of each light-emitting source present within the OR. The surgical light (Fig 2.b) produced the highest amount of signal amongst all sources in the NIR-I channel. Second to the surgical light, the NIR-I signal resulting from the infrared tracking system (Fig 2.d) was the most significant source of noise with wave pulses of IR signal readily captured within a 10 fps NIR-I frame sequence. Within the SWIR channel, the screens (Fig 2.a & c) surrounding the surgical bed generated a strikingly high amount of SWIR signal. Specifically, the large LCD wall monitor (Fig 2.a) and Navigation LCD monitor (Fig 2.c) generated an average of 3.18×10^5 cps and 3.20×10^5 cps, respectively, as measured directly by the SWIR imaging system positioned above the surgical bed at a typical working distance from the display screens.

Under each isolated background source condition, fluorescence images of the Spectralon reflectance standard along with average intensities measured from selected regions of interest can be seen in Fig 3.a. As mentioned previously, the surgical light contributes the most signal in the NIR-I channel, followed by similar signal contributions from the LCD screens and IR tracking system. In both the NIR-I and SWIR channels, the room ceiling lights contribute a very low amount of signal. On the other hand, the large LCD wall monitor

contributed the highest amount of signal in the SWIR channel (3.1×10^4 cps), followed by the Navigation LCD monitor (1.3×10^4 cps).

Fig 3.b presents the measured background signal measured on the reflectance standard under resulting from each signal-producing background source present within the OR room. The resulting plot reveals the SWIR signal from the LCD monitor to be the most significant source of background noise. Beyond the surgical overhead light, the LCD wall monitor and IR tracking system pose the greatest threat in the NIR-I channel (5,537 cps and 4,783 cps, respectively).

4. DISCUSSION AND CONCLUSIONS

From these results, a greater insight is provided into the potential sources of background NIR-I/SWIR signal to expect within an OR room. Amongst all sources evaluated, the SWIR photons originating from the LCD monitors constituted the most significant origin of background signal across all source and channel combinations. The positioning of each LCD screen with respect to the surgical imaging field obviously will affect how much incidental background SWIR signal is present while acquiring SWIR data.

While performing in-human open field fluorescence imaging, it is conventional practice to shut off all overhead surgical lighting. However, from this set of experiments, we conclude that other unsuspected sources of background signal within an OR room likely remain active such as LCD monitor screens and the IR tracking systems. Furthermore, while dark image subtraction may eliminate most of the incidental background noise, there are still dynamic sources of noise such as the IR tracking system's pulsed signal which may not be able to be completely corrected for in post-processing of fluorescence data. The findings presented here provide important guidance for implementing SWIR imaging systems in the OR.

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Figure 1. Schematic diagram of SWIR/NIR-I imaging system coupled to a 760 nm laser illumination source.

Figure 2.

NIR-I and SWIR images of fluorescence-emitting components typically found within a modern OR environment. Components shown include (a) LCD wall monitor (b) surgical light (c) Navigation LCD monitor and (d) an infrared tracking system.

Figure 3.

(a) Average reflective standard intensities measured under each condition and (b) resulting plot of measured intensities (cps) in both the NIR-I and SWIR channels.