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Review

Hand-held based near-infrared optical imaging devices: A review

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ABSTRACT

Near-infrared (NIR) optical imaging is a non-invasive and non-ionizing modality that is emerging as a diagnostic/prognostic tool for breast cancer and other applications related to functional brain mapping. In recent years, hand-held based optical imaging devices are developed for clinical translation of the technology, as opposed to the various bulky optical imagers available. Herein, we review the different hand-held based NIR devices developed to date, in terms of the measurement techniques implemented (continuous wave, time or frequency-domain), the imaging methods used, and the specific applications towards which they were applied. The advantages and disadvantages of the different hand-held optical devices are described and also compared with respect to a novel hand-held based device currently developed in our Optical Imaging Laboratory towards three-dimensional tomography studies.

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1. Introduction

Over the past three decades, near-infrared (NIR) optical imaging approaches have been developed for non-invasive tissue characterization and imaging. In particular, it has been emerging as a complementary imaging modality towards breast cancer based upon the endogenous absorption contrast owing to the non-specific process of angiogenesis, in order to discriminate normal from diseased tissues. NIR light between 700 and 900 nm wavelengths is minimally absorbed and preferentially scattered, allowing its propagation through deep tissues. While there are a number of imaging modalities used in clinical practice (e.g. X-ray, nuclear, magnetic

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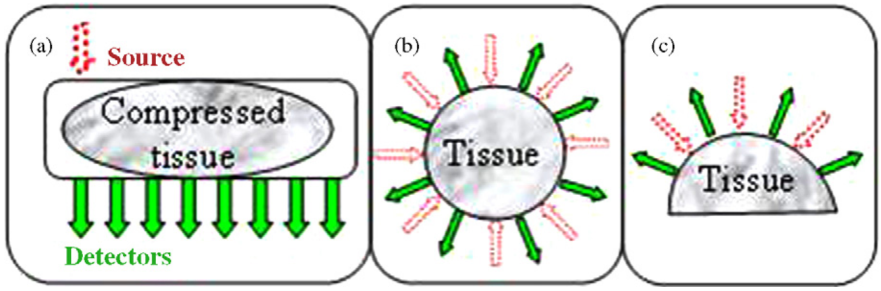

Fig. 1. Different imaging configurations: (a) compressed tissue, (b) circular, and (c) sub-surface.

resonance imaging (MRI), ultrasound), NIR optical techniques can be used to provide complementary information without the use of additional harmful radiation, radio-active substances, or bulky instrumentation (as in MRI). The promise of NIR optical imaging technology is based upon its ability to molecularly differentiate diseased tissues from healthy tissues that will help early diagnosis of rapidly growing cancers.

Most three-dimensional (3D) optical imaging studies towards breast cancer diagnosis employ either compressed tissue based imaging configuration [1–6] (Fig. 1a) or circular-based imaging configuration [7–22] (Fig. 1b). The compressed tissue based configuration is analogous to X-ray mammography, and is disadvantageous due to minimal patient comfort from tissue compression and limited information obtained around the complete breast tissue. The circular-based configuration has minimal patient discomfort, but is limited by the bulky and non-portable instrumentation. Sub-surface based imaging configuration (Fig. 1c) is a relatively new method that requires no tissue compression, and can be designed to mimic a portable and flexible imaging probe [21,23–64].

In recent years, hand-held based optical imaging devices employing the sub-surface imaging configuration are developed in an attempt to translate the technology to the clinic, with maximum patient comfort and portability (against the available bulky optical imagers). Different hand-held based optical devices have been developed by several research groups [21,26–64] with differences in the instrumentation, capabilities, and their specific applications. The current review will focus on all the hand-held based devices (termed hand-held imagers, probes, devices, and imaging systems by various researchers) developed to date towards optical imaging of biological tissues using NIR light. Table 1 gives a detailed summary of the different NIR hand-held devices developed to date in terms of the measurement technique, source and detector type, source wavelengths and input intensity, number of sources and detectors, target depth, and the number and type of subject studies. Herein, the different hand-held devices are primarily discussed in terms of: (i) the measurement technique employed; (ii) imaging methods implemented; and (iii) their specific applications, along with the advantages and disadvantages of the different systems available to date.

2. Measurement techniques in different hand-held optical devices

Optical imaging is typically carried out using one of the three measurement techniques, namely, continuous wave (CW), frequency-domain photon migration (FDPM), or time domain photon migration (TDPM). Different research groups developing hand-held based optical devices employed different measurement techniques based on their specific application and focus of research.

2.1. Continuous wave (CW)-based hand-held devices

CW-based measurement technique measures the attenuated light intensity that remains constant with time. Since only intensity is measured, the two optical properties (absorption and scattering coefficient) cannot be independently determined from CW-based imaging. Several of the hand-held devices developed for breast imaging employ CW-based measurement technique, although using different sources and detectors. A CW-based device developed at the University of Pennsylvania (Device #3, Table 1) employed light emitting diode sources (at three wavelengths) and silicon diode detectors [43–44]. Parallelly, a different CW-based device (Device #7, Table 1) was developed by another research group at the University of Pennsylvania [51,62], employing a long coherence laser source (four sources) and fast photon-counting avalanche photodiodes as detectors (four of them) coupled via detector fibers. In contrast, a hand-held device (termed as a tissue oximeter) developed at the Ohio State University (Device #6, Table 1) contained embedded laser diode and photodiode modules for CW-based NIR imaging [48,49,64].

Typically CW-based techniques are preferred over the time-dependent FDPM or TDPM measurement techniques, since the instrumentation is simple, inexpensive, and can be made portable towards developing hand-held based imaging devices. However, the CW technique provides limited depth information in comparison to the FDPM and TDPM techniques. This is because the technique only measures the changes in intensity, reflected from the combined effect of absorption and scattering (and not individually) [65–68]. In addition, if the CW-based hand-held devices were applied towards fluorescence-enhanced optical imaging studies, it would limit the technique from differentiating the changes in fluorescence intensity arising from the fluorophore concentration or its decay kinetics (i.e. fluorescence lifetime and quantum efficiency).

2.2. Frequency-domain photon migration (FDPM)-based hand-held devices

FDPM-based measurement technique measures the change in amplitude and phase of intensity-modulated light as it propagates through the medium. The advantage of frequency-domain systems is that both absorption and scattering information can be determined separately, since we measure a time-dependent parameter (i.e. phase shift) apart from the intensity (amplitude) of the detected signal. A disadvantage is that it requires a relatively extensive and bulky instrumentation set-up over the CW-based systems. Most of the hand-held devices developed towards breast imaging employ FDPM technique due to the above advantages. The following hand-held devices employ the FDPM measurement technique and are described in chronological order of device numbers in Table 1.