



Photoacoustic Imaging: A Promising Alternative to Transcranial Ultrasound

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Abstract

Photoacoustic imaging is a scalable functional and molecular imaging technique that can potentially be used for transcranial brain imaging as a complementary method to ultrasonography.

Keywords

Photoacoustic imaging; Transcranial brain imaging; Ultrasound

Background

Transcranial Ultrasonography is a clinically approved non-invasive and rapid technique for real-time measurement of the cerebral blood flow characteristics. This technique has become an integral part of detecting, monitoring and managing patients with vasospasm after subarachnoid hemorrhage due to aneurysm rupture [1-3]. Additionally, it has proved useful for evaluating the intracranial vasculature in patients with sickle cell disease, stroke, or brain death [1-3]. Based on the pulsed Doppler-Effect, transcranial ultrasound was originated in 1982 as a 'blind' non-imaging study [1-4]. Later, this technique has utilized the combination of color-coded duplex and pulsed wave Doppler ultrasound that allows the identification of the arteries in relation to various anatomic locations. This relatively inexpensive transcranial imaging technique involves the use of a low-frequency (≤ 2 MHz) transducer probe to insonate the basal cerebral arteries through skull bone windows [1-2]. These windows, commonly known as acoustic windows, are categorized into trans temporal, sub occipital (transforaminal), trans orbital, and submandibular (retromandibular). Among the pre-existing potential alternatives, intraoperative x-ray or CT may be used to navigate the bony anatomy [1,4-7]. Intraoperative magnetic resonance (MR) imaging is another costly option that is generally suffered from low resolution and deteriorated image quality due to the weak magnetic field [6]. Both MR and CT are not suitable for patients with pacemakers or metal implants [7]. Both techniques involve potential health risks because of the use of contrast material (e.g., anaphylactic reactions, nephrotoxicity) and exposure to ionizing radiation. In terms of flexibility, both of these procedures require that the patient be transported (generally from the intensive care unit) to the radiologic imaging department. None of these techniques provide continuous, real-time, intraoperative vessel visualization [4].

Even though the transcranial ultrasound has been considered to be the most convenient measurement technique that provides high temporal resolution real-time imaging, it requires low transmit frequencies for skull penetration. Lower operating frequency leads to degraded spatial resolution and necessitates expert sonographers to interpret images [8]. A real-time Doppler ultrasound probe was developed to assist surgeons with detecting carotid arteries, however failure was reported due to the incorrect interpretation of images where the doppler signals caused a misjudgment of the carotid artery location [5,9].

Photoacoustic Imaging (PAI) is a promising alternative to transcranial ultrasonography with functional and molecular imaging capability for a wide range of biomedical applications. PAI combines the technological advances of both optical and acoustic imaging, i.e., the high intrinsic contrast of optical imaging and the spatial resolution of ultrasound imaging [10]. Every material, including bodily substances, has a specific optical absorption coefficient unique to endogenous chromophores in cells or tissue. The substance to be imaged is illuminated by a nanosecond pulsed laser of a specific wavelength at which the absorption coefficient of the absorbing molecules in the subject is the highest. This absorption results in the generation of internal acoustic wave via the thermo-acoustic effect. The initial amplitudes of the induced acoustic wave is proportional to the spatially variant absorbed optical energy density in the tissue. The acoustic waves propagate through the tissue and are subsequently detected by use of a collection of wide-band ultrasonic transducers that are located outside the object. A reconstruction algorithm is employed to estimate the initial induced pressure distribution. The optical contrast is dependent on hemoglobin concentration and related to the molecular constitution of tissue for which PAI is capable of revealing the pathological condition of the tissue [11] and therefore facilitate a wide-range of diagnostic tasks.

Photoacoustic imaging is a scalable imaging technique, i.e., from photoacoustic microscopy (PAM) with microns resolution and millimeters penetration depth, to photoacoustic computed tomography (PACT) with hundred microns resolution and centimeters penetration depth [12]. Due to less acoustic attenuation because of the less acoustic interaction with skull, signal detection with photoacoustic imaging is expected to be advantageous over conventional ultrasound imaging. Generated acoustic wave due to optical absorption is required to travel through the skull one-way unlike in pulse-echo ultrasound. As a result, the waves are less susceptible to the sound scattering and aberrations that occur when they encounter the skull-tissue interface. Functional information of HbT and sO_2 within micro-vessels can be imaged using a dual-wavelength measurement [13,14]. The major challenges in transcranial imaging are the strong optical and acoustic attenuation of skull due to scattering, distortion, and aberration.

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