**PHOTOACOUSTIC IMAGING**

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**ABSTRACT**

*Photoacoustic imaging or optoacoustic imaging is a biomedical imaging modality based on the photoacoustic effect. By introducing non-ionizing laser pulses into biological tissues, some of the energy is transformed into heat, which causes the tissues to briefly release ultrasonic vibrations. Images are produced by processing these waves, which are picked up by ultrasonic transducers. The intensity of the ultrasonic emission, which represents local energy absorption, highlights physiological features like oxygen saturation and hemoglobin content that are correlated with optical absorption. This makes it possible to create 2D or 3D images of desired regions with optical absorption contrast that is medically specific.*

**INTRODUCTION:**

At its core, photoacoustic imaging involves the use of laser-generated ultrasound waves. The process begins when a short laser pulse is directed at tissue. Biological tissues may absorb light due to exogenously supplied contrast agents or endogenous substances like melanin or hemoglobin. The optical absorption spectra of deoxygenated hemoglobin (Hb) and oxygenated hemoglobin (HbO2) in the visible and near infrared range, for instance. Blood often absorbs light at a rate that is orders of magnitude higher than that of surrounding tissues, thus endogenous contrast is adequate for photoacoustic imaging to see blood vessels. According to recent research, photoacoustic imaging can be utilized in vivo for methemoglobin measurement, functional brain imaging, blood oxygenation mapping, skin melanoma detection, tumor angiogenesis monitoring, and more.

There are two different kinds of photoacoustic imaging systems that have been developed: photoacoustic microscopy (PAM) and photoacoustic/thermoacoustic computed tomography (PAT/TAT). In a conventional PAT system, the photoacoustic signals are obtained using an unfocused ultrasonic detector, and the photoacoustic equations are solved inversely to reconstruct the image. In contrast, a PAM system does not require a reconstruction technique and employs a spherically focused ultrasonic detector with 2D point-by-point scanning.

**PHOTOACOUSTIC MICROSCOPY:**

Photoacoustic microscopy (PAM) is a hybrid in vivo imaging technique that acoustically detects optical contrast via the photoacoustic effect. In contrast to pure optical microscopic methods, PAM surpasses the optical diffusion limit (~1 mm in soft tissue) by utilizing the mild sonic scattering present in tissue. PAM's outstanding scalability enables it to provide high-resolution pictures at the targeted maximum imaging depths of a few millimeters. PAM offers absorption contrast rather than scattering contrast when compared to backscattering-based confocal microscopy and optical coherence tomography. PAM is also capable of imaging a greater number of molecules—endogenous or exogenous—at their absorbing wavelengths than fluorescence-based techniques like multi-photon, confocal, and wide-field microscopy. Above all, PAM has the ability to visualize in vivo contrasts related to anatomy, function, molecules, flow dynamics, and metabolism all at once.

**PHOTOACOUSTC TOMOGRAPHY**:

Photoacoustic tomography (PAT, also referred to as optoacoustic tomography) has proven capable of multiscale imaging with a consistent contrast mechanism; thus, it is uniquely situated to bridge the microscopic and macroscopic domains in the life sciences. PAT is a hybrid imaging modality that acoustically detects optical absorption contrast via the photoacoustic effect.

In PAT, the imaging process typically starts with a short laser pulse fired at biological tissue. As photons propagate into the tissue, some are absorbed by biomolecules (e.g., hemoglobin, DNA/RNA, lipids, water, melanin, and cytochrome), and their energy is usually partially or completely converted into heat through nonradiative relaxation of excited molecules. The heat-induced pressure wave is detected outside the tissue by an ultrasonic transducer or transducer array to form an image that maps the original optical energy deposition inside the tissue. PAT has a 100% relative sensitivity to small optical absorption variations, which means a given percentage change in the optical absorption coefficient yields the same percentage change in the PA signal amplitude. By contrast, back-scattering-based confocal microscopy has a relative sensitivity to optical absorption of only ~6% at 560 nm and ~0.08% at 800 nm in blood. Because PAT does not rely on fluorescence emission of molecules, which usually has a quantum yield less than 100%, it can image nearly all molecules, fluorescent or not.

The seamless combination of optical excitation with ultrasonic detection offers three striking advantages:

(1) PAT is maximally sensitive to the rich optical absorption contrast of biological tissue, and it is inherently well suited for functional, molecular, metabolic, and histologic imaging through endogenous contrast and for molecular and neuronal imaging through exogenous contrast.

(2) Because biological tissue is orders of magnitude more transparent to sound than to light in terms of scattering mean free path, PAT provides far greater penetration with a scalable spatial resolution than optical microscopy.

3) PAT is highly complementary to and compatible with other imaging modalities, especially optical imaging, and ultrasound imaging. PAT-enhanced multi-modal imaging can provide rich complementary contrasts for comprehensive understanding of biological phenomena.

**CLINICAL AND PRICLINICAL APPLICATIONS**:

* In the clinical setting, PAI is promising in areas such as oncology, where it can detect and monitor tumors. Because tumors frequently have newly formed, leaky blood vessels and a greater metabolic rate than healthy tissue, PAI can identify the unique optical absorption features of tumors. This capacity to distinguish between healthy and sick tissue is essential for therapy monitoring and early diagnosis.
* Cardiology is another area where photoacoustic imaging is finding usage. It can be used to see atherosclerotic plaques, which are prone to rupture and result in heart attacks. By using PAI to identify the distinctive absorption spectra of the lipids present in these plaques, it may be possible to identify high-risk plaques before they pose a clinical issue.
* PAI in neurology can help comprehend neurovascular connections and brain function. Given the strong relationship between neural activity and variations in blood volume and oxygenation, photoacoustic imaging can be used to study dynamic cerebral processes with high spatial and temporal resolution.

**TECHNICAL CHALLENGES AND FUTURE DIRECTIONS:**

* PAI has numerous benefits, but it also has certain technical difficulties. The photoacoustic signal's attenuation and distortion as it passes through diverse tissues is one of the main obstacles. This may make the process of reconstructing the image more difficult and result in a lower-quality final image. To solve these problems, sophisticated signal processing methods and algorithms are being created.
* Due to the usage of finite-sized transducer arrays, there is also the limited view problem, which can lead to incomplete data and artifacts in the reconstructed images. Creating innovative transducer designs with wider detection angles and more sensitive detection materials are two ways to find solutions.
* The future of photoacoustic imaging involves overcoming these technical challenges and translating the technology from the laboratory to the clinic. This translation requires the development of portable, user-friendly, and cost-effective PAI systems. There is also a significant potential for multimodal imaging approaches that combine PAI with other imaging modalities, such as MRI or ultrasound, to provide complementary information about tissue structure and function.

Furthermore, the field is exploring the development of targeted contrast agents that can provide molecular-level specificity. These agents are designed to bind to specific biomolecules and enhance the photoacoustic signal, thereby enabling the imaging of a wide range of biological processes.

**CONCLUSION:**

Photoacoustic imaging stands at the intersection of optics, acoustics, materials science, and biology, and it harnesses the strengths of each to peer into living tissues with unprecedented clarity. As researchers and clinicians continue to develop and refine this technology, PAI is poised to significantly impact how we diagnose and understand a wide range of diseases. Its ability to provide real-time, high-resolution insights into the molecular and structural composition of tissues could revolutionize the fields of medical imaging and diagnostics, leading to earlier detection and more personalized treatments for various health conditions. As the technology matures, the promise of non-invasive, safe, and detailed visualization of the body’s interior is an exciting prospect, bringing a new dimension to medical imaging capabilities.