BIOMEDICAL OPTOACOUSTIC TOMOGRAPH BASED ON A CYLINDRICAL FOCUSING PVDF ANTENNA

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We developed an optoacoustic tomograph with hand-held probe designed for optoacoustic imaging of biological tissues. The hand-held probe consists of a fiber-optic bundle for delivery of pulsed laser radiation to the studied object and a cylindrical focusing 64-element antenna for the detection of optoacoustic pulses. The capabilities of the tomograph to visualize the model blood vessels were studied experimentally using electronic and electronic–mechanical scanning. The achieved axial/lateral spatial resolution is 200/400 µm, the imaging depth is 18 mm, and the maximum B-scan acquisition rate is 10 Hz.

1. INTRODUCTION

Optoacoustic (OA) diagnostics is an advanced method of biomedical imaging, which is based on recording of ultrasound waves excited in the studied medium when the pulsed laser radiation is absorbed by inhomogeneities [1]. The main advantage of the OA methods of biological-tissue imaging over the diffusion optical methods [2] is a better spatial resolution [3]. In comparison with coherent optical methods [4], OA imaging provides an increased depth of diagnostics (up to a few centimeters) [5]. In comparison with the methods of active ultrasound location [6], OA imaging gives a better contrast of images. The possibility to implement completely optical or completely ultrasound methods as a result of minor improvements of the OA setups should also be mentioned [7–9].

To obtain high-contrast images of the light-absorbing structures of the studied biological tissue, the OA setups use modern pulsed lasers with tunable wavelength of the radiation [10]. Thus, there is an opportunity for optimizing the OA contrast of endogenous or exogenous contrast agents, which makes angiography possible [11] and allows one to determine the oxygen status of blood in individual blood vessels [12] and visualize the soft-tissue neoplasms [13]. Currently, the OA methods continue to be improved and are used in many medical applications.

There are two methods of OA imaging: tomography and microscopy. In OA microscopy [15], a single receiver moves along the surface of the medium and records optoacoustic A-scans at each scanning point, which permits one to obtain 3D images using reconstructive algorithms [16]. Optoacoustic microscopy is based on mechanical scanning of the studied object by the focal waist of a single-element spherical focusing antenna. To form an image composed of a given number of A-scans, a single-element OA scanner requires the same number of laser pulses. For example, when a laser with a pulse repetition rate of 10 Hz is used [17], the formation of a 2D image of 600 A-scans takes 1 min, which significantly complicates the prospects for in vivo diagnostics [18]. One of the methods for reducing the OA imaging time is the use of multi-element

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acoustic antennas which permit synchronous data acquisition in several channels, i.e., make OA tomography possible [19, 20].

The paper presents an optoacoustic tomograph based on a cylindrical focusing polyvinylidene fluoride (PVDF) antenna [21, 22]. A PVDF piezoelectric film is a commercially available material, which is flexible and easy to process, allowing to put it into an arbitrary shape that ensures the focusing properties of the PVDF antennas without using acoustic lenses. In addition, the film has a high adhesion and a high resistance to mechanical and chemical impacts. The acoustic impedance of PVDF (4 Mrayl) differs from the acoustic impedance of water by only a factor of 2.6 (e.g., in contrast to the acoustic impedance of piezoceramic materials, which differs from the water impedance by more than 10 times). In comparison with piezoceramic materials, PVDF also ensures recording of acoustic signals over much wider ranges of acoustic frequencies, which makes it possible to achieve a better spatial resolution. Thus, the high-frequency acoustic sensors based on PVDF films have an improved performance at a lower or comparable cost.

We give the results of experimental studies of the capabilities of an OA tomograph by imaging the model blood vessels in electronic and electronic–mechanical scanning modes. Mechanical scanning means successive motion of a multi-element antenna with a laser-pulse repetition rate. Electronic scanning is successive connection of the elements of a multichannel antenna to the data acquisition system.

2. MATERIALS AND METHODS

A block diagram of the optoacoustic tomograph developed at the IAP RAS is given in Fig.1. A photograph of a portable optoacoustic head, which can be freely held by the hand of a diagnostic physician in