Passive Acoustic Thermometry of the Chest of a Person with COVID-19

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Abstract—Passive acoustic thermometry (PAT) was used to study the dynamics of changes in the chest temperature of a person with COVID-19 over the course of about two and a half weeks after quarantine. PAT, which can measure deep body temperature, showed that the integral temperature of tissues surrounding the lungs increased from $32.2 \pm 0.07$ to $33.0 \pm 0.03^\circ C$ about 10 days after the end of quarantine. This may indicate increased blood supply to the lungs, i.e., an indication of recovery. Infrared thermometry used to monitor recovery yielded no results.

Keywords: passive acoustic thermometry, thermal acoustic radiation, acoustobrightness temperature, IR thermometry, COVID-19

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INTRODUCTION

Currently, a significant number of people have been afflicted with pneumonia stemming from the COVID-19 pandemic. A particular problem is the search for objective methods to monitor patient recovery from COVID-19–related pneumonia. To diagnose and objectively monitor the disease during treatment, proven medical methods are used, including those involving X-ray examination, the associated risks of which seem justified in light of the valuable information obtained. However, frequent use of X-rays to monitor patient recovery is undesirable, therefore requiring other monitoring methods. For pulmonary pathologies, blood supply to the lungs and bronchi deteriorates, which can cause a decrease in temperature. Thus, pulmonary thermometry after a patient is discharged may provide information about restoration of blood supply to the lungs and ultimately about the patient’s recovery from pneumonia.

Passive acoustic thermometry (PAT) can be recommended to solve this problem, which records the human body’s own thermal acoustic radiation in the megahertz range [1–5]. Calculations [6] and model experiments [7] show that the proposed method can measure temperature at a depth of 3–8 cm, in a volume of about 1 cm$^3$, with an accuracy of 0.5–1 K over a time of ~1 min. If acoustic thermometry of a patient’s chest and back is performed, then muscle, connective, and bone tissue and air-filled lungs will be located under the measuring sensor. However, due to large reflection, an acoustic signal cannot penetrate the human body from the air. A similar situation occurs at the bone–soft tissue interface: any acoustic inhomogeneity scatters the signal. What is then recorded is multiply scattered acoustic radiation from soft tissues between the surface of the skin and lungs. The measured signal carries information about the temperature of these tissues, which also depends on the temperature of the lungs, which in turn depends on blood supply to them.

Note that PAT has already been used in medical research: laser hyperthermia of the mammary and thyroid glands was performed at the Central Clinical Hospital, Russian Academy of Sciences [8]; at the Burdenko Research Institute, the brain temperature of patients with partially missing skull bones was measured [9]. Measurements were taken during UHF heating of patients’ hands [10] and during glucose tests [11].

Infrared thermometry (IRT) was also used to monitor changes in lung temperature. IRT provides information on skin surface temperature and is mainly determined by the near-surface blood flow, which partly depends on the temperature of the underlying tissues [12]. Therefore, we hoped that these data could also be used to obtain information on deep temperature.

The objective of the study is to measure temperature variations of a torso of a COVID-19–afflicted patient and to show that PAT can be used to objectify the patient’s recovery process.
MATERIALS AND METHODS

The research involved patient A (59 years old), who had been ill with COVID-19. Said patient was in the hospital and had twice been examined by multislice X-ray computed tomography, which confirmed a bilateral lesion on lung tissue. On the 16th day after onset of first symptoms, patient A was discharged and quarantined for another 14 days, after which the patient returned to normal life. Measurements were taken between the days 31 and 47 after the onset of symptoms with a frequency of 2–3 days between measurements. IRT to obtain monitoring data involved noninfected patient B.

To measure thermal acoustic radiation, a multichannel acoustic thermograph was used [13], developed at the Institute of Applied Physics, Russian Academy of Sciences (bandwidth 1.6–2.5 MHz, threshold sensitivity for an integration time of 10 s, 0.2 K). The received acoustic signals were converted into electric signals, which were amplified, passed through a quadratic detector, and averaged over 30 ms. From the outputs of the multichannel acoustic thermograph, the signals were fed to a 14-bit multichannel E14-140 ADC (ZAO L-Card, Moscow, Russia) at a sampling rate of 1 kHz per channel. The developed program subsequently averaged the data.

Acoustic measurements were carried out as follows. The sensor was mounted on an acoustic blackbody at room temperature. The holder temperature was controlled by DS18S20P digital thermometers (Maxim Integrated, San Jose, USA) with an accuracy of 0.3 K. Mediagel ultrasound research gel was applied to the surface of the object. For 10–15 s, thermal acoustic radiation from the area of the body was measured. Afterward, the sensor was returned to its holder.

The acoustobrightness temperature was measured at eight points, four on the chest and four on the back (Fig. 1). Each measurement was repeated three times. The average acoustobrightness temperature of the lung zone was obtained by averaging the data at all eight points. The average chest temperature was obtained by averaging data points 1–4. The average back temperature was obtained by averaging the data at points 5–8.

The surface temperature was measured with an IRTIS-2000 portable computer thermograph (Irtis, Moscow, Russia) with a temperature difference sensitivity (at the level of 30°C) of 0.05 K; the device records thermal electromagnetic radiation in the IR range, 3–5 μm [14]. IR thermograms of two patients were taken from the side of the chest and from the back. The patients were at a distance of 1.5 m from the thermograph’s camera, set up at chest level. In each measurement, five frames were obtained for both the chest and back. All recommendations for the room, equipment setup, and patient preparation for IRT were implemented as specified in [15]. The computer program supplied with the device made it possible to image the temperature distribution over the surface of the patient’s body and was also used to calculate the average temperature in the rectangular area shown in Fig. 1.

Room temperature was determined using the background of IR thermograms.

RESULTS AND DISCUSSION

The acoustobrightness temperature of an object (area of the human body) was measured—an integral characteristic equal to the temperature of an acoustic blackbody that generates the same thermal acoustic radiation flux density as the studied object [16]. Figure 2, for example, shows the time dependence of the acoustobrightness temperature of the patient obtained 47 days after onset of illness. A low signal level of 19.2 ± 0.2°C corresponds to the acoustobrightness temperature of the holder, which is close to room temperature. A high level of 33.1 ± 0.3°C indicates the acoustobrightness temperature obtained in position 8 (Fig. 1) on the patient’s back.

Figure 3 shows the time changes of the measured acoustobrightness temperature. The following experimental dependences were obtained: the average temperature of the lung zone (curve 1) increased on day 38 from onset of disease, from 32.2 ± 0.07 to 33.0 ± 0.03°C, and reached a constant level. In the first measurement period, from day 31 to 38, the average acoustobrightness temperature from the side of the chest (curve 2) was 0.86 ± 0.11°C less than the average back temperature (curve 3); then these temperatures equalized: the difference was −0.04 ± 0.12°C. The correlation coefficient for the average acoustobrightness temperature and room temperature is −0.14; i.e., there is no correlation.

Figure 4 shows the IRT results for the rectangular area shown in Fig. 1. The time dependence of the average IR temperature of patient A prevents identification of any trend. Apparently, this is because the IR temperature of the skin surface strongly depends on external factors, which masks the desired trend, or there is simply no trend. To minimize the effect of changes in room temperature, IR thermograms of patient B were obtained (see Fig. 4) and the differences in IR temperatures in the studied areas of patients A and B were calculated (Fig. 4). The time dependence of the temperature difference also revealed no trend. Similar IRT was carried out from the side of the chest in both patients, which yielded no results either. The data indicate the impossibility of using IRT to objectify the recovery process of a patient who has had pneumonia.

The possibility of using IRT for diagnosing pneumonia has been discussed for several decades (e.g., [17, 18]), and currently, the scientific community treats this idea with skepticism. We found no studies on the use of thermometry to monitor the recovery process.
Fig. 1. Typical thermogram of patient A from chest and back. Areas (1–8) where acoustic receivers were placed and rectangular area for IRT are shown.
The obtained acoustic thermometry data show that the average temperature of the torso of patient A increased on day 10 after the end of quarantine (or on day 40 after the onset of symptoms). This may indicate improved blood supply to lung tissue, possible evidence of a previously ill person’s recovery.

A limitation of PAT is that it is still being developed. An ideal study would include magnetic resonance thermometry as a reference method for measuring deep temperature for comparison the PAT results. In theory, it is also possible to administer thermometer-equipped needles into patient muscle tissue for monitoring, but the organizers of the study have resolutely refused such experiments. Note that the PAT is much more practical and cheaper than magnetic resonance thermometry.

As well, our study is preliminary: one patient does not allow us to draw statistically valid conclusions, which, however, was not the objective here. We aimed to show that the use of PAT to measure lung tissue temperature in a person who has had COVID-related pneumonia can yield objectified information about the patient’s recovery. We worked with test patients who had had COVID-19 and gone through a rehabilitation period. However, it is possible that the recovery process was still ongoing at that time, and, it seems to us, we were able to trace this.

Further improvement in the methodology will obviously be associated with an increased sampling size, which would be an independent verification of our conclusions. Our study only indicates one possible direction for future research.

COMPLIANCE WITH ETHICAL STANDARDS

All procedures performed in human research comply with the ethical standards of the Institutional Research Ethics Committee and the 1964 Declaration of Helsinki and its subsequent amendments.

Informed voluntary consent was obtained from each of the participants.

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