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Intracavity Thermometry in Medicine

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We present here an analytical review of technical means used for intracavity thermometry of biological objects. Radiometers can be effective both in medicine and veterinary medicine. The opportunities for determining the 3D distribution and dynamics of brightness temperatures measured though natural cavities in the human body are discussed.

Introduction

All current studies in medical thermometry run in two directions: development of intracavity temperature sensors to measure temperature through natural biological cavities and abdominal sensors to measure body temperature through the skin. Studies involving acquisition of information on intracavity temperatures within natural biological cavities and their adjacent organs are of ever greater practical interest, as temperature is one of the first signs of pathological changes in the human body. For medical purposes, surface and internal (intracavity) temperatures are measured. Intracavity body temperature is more stable and less subject to environmental influences. Measurements of intracavity temperatures can provide unique diagnostic information. The aim of this work was to provide an analytical review of devices used for measurement of temperature through biological cavities in the body and to evaluate the potential for the use of microwave radiometers for intracavity thermometry.

Measurement of tissue temperature through natural body cavities requires temperature sensors of minimal size, as insertion of the measuring device into cavities may produce trauma. The most widely used device for measuring the temperature of biological objects is infrared thermography, which visualizes the temperature of biological tissues of thickness up to 100 μm. Measurement of intracavity temperature can use a variety of sensors: thermocouples, IR probes, and other contact sensors. Contact devices can be used to measure temperature only at the point of direct contact with the mucosa (the contact must be reliable). Microwave radiometry, based on recording of the power of intrinsic electromagnetic radiation, provides temperature measurements from deep biological tissues [1]. It is well known that the internal temperature of biological tissues can also be measured by other methods, such as MRI, acoustic thermometry, the zero heat flow method [2], as well as thermometry using terahertz radiation [3]. However, use of MRI requires access to complex and expensive medical technology. As for the other three methods, further studies are needed and it is too early for them to be introduced into the healthcare system as intracavity thermometry methods [4]. The minimum tumor size that can be diagnosed using conventional diagnostic methods is 15 mm in diameter [5]. The impossibility of early detection of pathology is a major cause of failures in treating tumors that start to metastasize at smaller sizes [5], so the search for sensitive methods allowing diagnosis of tumors of minimal size is relevant. These methods include microwave radiometry.

Intracavity thermometry includes a series of methods of measuring temperature: transrectal, transvaginal, oral, etc. Another approach is infrared tympanic ther-

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mometry. Each measurement method has its advantages and drawbacks, as described in [6, 7].

The authors of [8] determined the normal daily range of axillary and rectal temperatures in infants during the first six months of life. Rectal and axillary temperatures were measured in the daytime in 281 children who were randomly examined at home and 656 children examined in hospital at age up to six months using glass mercury thermometers. Rectal temperatures were higher than axillary temperatures in 98% of cases; rectal thermometers also had greater sensitivity. These results led to the conclusion that better temperature measurements are obtained in children using the rectal method.

One of the main methods of maintaining and monitoring female health is intravaginal temperature measurement. Temperature monitoring allows menstrual cycle stages to be followed and various causes of infertility and other pathological processes to be established. Various types of IR probes and contact temperature measuring devices introduced into the body can be used for this purpose [9]. In particular, an intracavity device [10] for intravaginal temperature monitoring has been developed. The device consists of two main parts: a temperature sensor and a processor. There is also a computer app for analysis of temperature measurements. This device can be used alongside an intravaginal temperature monitoring system with a mobile phone running the Symbian operating system [11]. A woman can follow changes in temperature in real time or offline, thus identifying ovulation, menstrual cycle features, and the most favorable moment for planning pregnancy. The same group reported [12] studies of a wireless sensor for measuring and monitoring intravaginal temperature with the aim of determining ovulation. Other studies from this group have been described in [13, 14]. Intracavity probes [10-14] for temperature monitoring do not provide complete information on the presence of pelvic pathology, and also fail to provide for investigations of other parts of the pelvis; they were created to study female fertility, determine ovulation, and plan pregnancy. Report [15] presents a means of measuring temperature using multiple wireless sensors connected to form a single network. The resulting data are used in studies of temperature interactions and various processes in the human body, such as biorhythms.

Patent [16] described an intracavity measuring device in the form of a ring. A flexible ring 50-80 mm in diameter is positioned directly in front of the cervix and a tampon is placed in the vagina. Measurements are made every 1-5 s for 6-48 h in autonomous mode. This design includes a battery and a wireless transmitter. The device can use the following types of sensors: tensometer, pH meter, pulsoximeter, thermometer, etc., and has a reservoir for drug delivery. The main function of the device is to investigate dysfunction of the female reproductive organs.

Basal body temperature was measured in [17] to determine ovulation. It used an alternative method based on a telemetry thermometer. The thermometer is an active transvaginal probe in a tampon-like sheath built on the basis of a low-power temperature measurement circuit. It includes a single-stage surface acoustic wave resonator and a pulse–amplitude modulation transmitter operating at a frequency of 418 MHz. The bedside base station contains a specific receiver with a microcontroller connected to a clock, recording temperature every night with an accuracy of 0.1°C during a specified period. Initial clinical results have demonstrated high effectiveness of transvaginal thermometry as compared with oral and axillary thermometry using a mercury glass thermometer.

The authors of [18] performed intravaginal thermometry at night in the absence of menstruation using an OvuSense system to detect atypical patterns associated with reduced fertility. The study involved 6647 women aged 20-52 years with cycle durations of 11-190 days. A total of 10,463 ovulation cycles were studied. The experiment took account of age and the times at which the women tried to conceive. The system measured temperature every 5 min, with subsequent computerized data processing. The main criteria for assessing the results was the proportions of normal and atypical time patterns, their frequencies, and relationships between patterns. This resulted in identification of three novel atypical temperature patterns. Constant intravaginal temperature reflected luteal changes in progesterone, so anomalies in progesterone secretion or metabolism which had not previously been recognized were described. Intravaginal temperature monitoring is therefore a promising method for detecting the causes of infertility in women with "normal" ovulation.

The technical procedures for the keeping and reproduction of agricultural and domestic animals require operational monitoring of physiological indicators. This is particularly relevant in large farms, where all animals are under veterinary monitoring. One component of this monitoring may consist of intracavity monitoring. For example, a Japanese group carried out continuous measurement of intravaginal temperature in cows using a wireless sensor with subsequent prediction of the onset of calving and determination of the relationship between dystocia, the condition of the calf, and changes in temperature at particular times [19]. The sensor was inserted in the vagina seven days before the presumptive date of delivery and collected temperature information every

5 min. This study identified a number of predictive patterns. The first warning was a drop in vaginal temperature by 0.4°C over 4 h as compared with other days. The second was a drop in temperature to the environmental temperature during rupture of the allantoic sac. The levels of detection of warnings 1 and 2 were 88.3% and 99.4%, respectively. The mean time between warnings 1 and 2 was 22 h; the time between warning 2 and delivery was 2 h. These results showed that monitoring of intravaginal temperature was effective in predicting calving time. These data could also be used to assess the severity of labor, which correlates with dystocia, body weight at calving, sex, and gestational age. The results showed that calf weight is the most important risk factor for dystocia and that constant temperature measurement may be a good indicator predicting the onset of calving and the need for assistance with delivery. Other uses of intracavity thermometry in veterinary medicine are presented in [20-23].

Microwave radiometers are already used in gynecology and other areas of medicine. Microwave thermographs fitted with special intracavity antennas and using special software for 3D imaging of temperatures in biological cavities of complex shape are suitable for solving intracavity thermometry tasks. Intracavity use requires creation of small devices based on modern components and using new technologies [5, 24-29]. The pelvic organs are located at some distance from the wall of the abdominal cavity, so abdominal wall temperature is generally not increased when pathology is present. Thus, for example, transabdominal investigation of the uterus with antennas placed on the abdominal cavity gives only indirect data on processes occurring in the pelvis. Use of standard transabdominal medical antennas is also of little value for detecting diseases of the pelvic organs, because of the distance of the pathology foci from the body surface. Construction of intracavity antennas must also allow determination of the depth to which they are inserted into the cavity and where the focus of elevated temperature is located. Studies reported in [30] used a radiometer with a single-channel intracavity antenna and a standard waveguide antenna. Studies were run transabdominally and transvaginally. Temperature measurements were recorded in the projection of the adnexa, the base and anterior wall of the uterus, and the cervix uteri. The authors noted that thermometry using a transvaginal sensor allowed diagnosis not only of acute exacerbations of chronic salpingo-oophoritis and inflammatory processes in the adnexal area with complex courses, but also subacute salpingo-oophoritis, in contrast to investigations using a transabdominal sensor. Overall, the authors regarded radiometry as a highly informative additional method in the overall algorithm for investigating patients with inflammatory diseases of the adnexa and benign ovarian tumors.

Intracavity thermometry has an important role as a method for monitoring various types of therapeutic process, such as microwave hyperthermia. Patent [31] presented an intracavity endoscopic apparatus for local heating of superficial tissues using a microwave emitter. The apparatus contained an integrated radiometer providing for detection of temperature differences arising as a result of different levels of heating of tumors and surrounding tissues. Patent [32] presented a method of treating prostate diseases, where tissues had previously been removed by transurethral resection surgery. The emitting device is integrated into a Foley catheter and can also be used to record thermal irradiation power to monitor prostate heating. The urethral applicator is a multichannel tube and a balloon catheter. Patent [33] presented a microwave thermometer with an intracavity applicator consisting of a catheter with two microwave antennas for measuring the temperature difference between two points in the patient's tissues for tumor detection. The applicator is slowly introduced into the patient's urethra to reach the area of the prostate, which may be the location of a tumor. Measurements are used to construct a plot of temperature changes along the whole of the urinary channel. Increases in temperature are used to determine not only the fact of a thermal anomaly, but also the distance at which it is located, i.e., the position of the tumor. These technical solutions are invasive methods and require highly qualified staff. The most developed system for use in urology and gynecology is the three-channel intracavity antenna [34]. This antenna can be integrated into a microwave radiometer to visualize the internal temperature of a biological cavity in three-dimensional mode by measuring intracavity and surface temperatures, which is more informative than the method described in [31].

Use of radiometric devices for intracavity thermometry has its specific features and imposes certain requirements on the circuits and designs of the radiometers used [29, 34]. In addition, measurement of parameters in human cavities using single-channel and single-frequency devices is not always appropriate and does not provide the required accuracy for temperature measurements in cavities and adjacent organs. There is therefore a need to use multichannel antennas or multifrequency modules with single-channel or multichannel antennas with miniaturization of the modules themselves, which can be achieved using microwave monolithic integrated circuits.

The use of novel circuit solutions in SHF radiometers and state-of-the-art components significantly reduces the volume of a single measurement channel. This allows radiometers to be built using various electrical circuits depending on the medical task to be solved. Overall, the use of microwave radiometers allows a number of important aims to be achieved: sources of thermal inhomogeneities can be located; responses to physical and chemical factors can be recorded during investigations; spatial frequency responses can be documented and relationships between the parameters of these characteristics and the physiological indicators of human tissues and organs can be established; treatment can be corrected on the basis of changes in electromagnetic tissue and organ irradiation parameters. Final selection of the number of channels and frequency ranges, the types of sensors used (antenna design), investigation methods, and interpretations and visualizations of results, computational and software solutions for data processing must be carried out only in conditions of medical testing jointly with doctors during the process of diagnosis and treatment of various diseases in the course of routine medical investigations. This requires relevant and competent medical collaborators to participate in future studies, with access to current innovatory infrastructure.

Conclusions

Microwave radiometers hold the greatest promise for intracavity thermometry. Thus, measurement of tissue temperature distribution via natural body cavities is a very relevant task. Medical radiometers have to meet specific requirements, particularly for miniaturization, number of channels, working frequencies, antenna design, and casing shape. The use of intracavity thermometry has potential in areas such as fertility assessment for planning pregnancy, primary diagnosis of oncological diseases, monitoring of biological parameters, and many others. On these grounds, we can conclude that there is a need for further research to increase the information value of intracavity radiometry.

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