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The procedure for measurement of the human temperature field dynamics

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Abstract

The absence of an established standard both for remote measurement of the dynamics of temperature fields on the surface of the human skin and for corresponding data processing is one of the serious reasons limiting the using of a unique non-invasive thermal imaging method in clinical medicine. We proposed an original procedure for measuring and quantifying the temperature data array obtained by thermal imaging examination of a group of cancer patients during the course of radiation therapy (RT). This procedure is intended as well as for quantitative monitoring of the current level of local side effect (oral mucositis — OM) of the patients treated with RT and for the early prediction of individual patient's tolerance to irradiation. Because of human thermoregulation characteristics, a relative temperature scale was used for each patient for quantitative estimate of the skin radiation intensity. The average temperature over a specific region is chosen as the reference temperature, also the temperature field in area of interest of each patient prior to RT start is chosen as the baseline. The accuracy of the relative temperature measurements is determined by the temperature sensitivity of the thermal imaging system $\Delta T \approx \pm 0.07$ °C. The correlation coefficients $R = (0.76 \div 0.81)$ between the thermal and clinical parameters as well as the index "good quality" (AUC = 0.79) of prognosis method have been obtained. These results indicate the possibility of using proposed approach for measuring and processing the dynamical temperature field data on the human skin surface including for quantitative monitoring and prediction of the level of side toxic reactions in patients treated with RT. The authors note the study should be continued to increase the statistical power of the results.

Keywords: infrared thermal imaging, temperature remote measurement, medicine.

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Introduction

Today, in clinical medicine there is no accepted standard for remote measurement of the dynamics of temperature fields on the surface of the human skin and quantitative processing of the temperature data. As usually, the results of the thermal imaging examination are presented as thermograms with the indicated clinical diagnosis established by other medical methods. In most cases, the quantitative analysis of thermal data is limited to the absolute temperature scale placed under the thermogram or absolute temperature values marked at the points of interest on the thermogram [1]. However, the thermal field of the skin of even a healthy person is constantly changing in time caused by various external and internal factors in accordance with the individual features of thermoregulation. In case of a disease, specific additional abnormal thermal fields appear, caused, for example, by fever and other manifestations of a pathological condition. Therefore, the authors consider it incorrect to use the absolute temperature scale in medical thermography. Moreover, an accuracy of absolute temperature remote measurement does not exceed 2 % of the measured temperature (i. e. $\delta T \approx \pm 0.7$ °C for human temperature range), while the accuracy of relative temperature measurements is determined by the temperature sensitivity of the used thermal imaging device, so the error does not exceed ($\delta T \approx \pm 0.1$ °C).

Analysis of recent researches and publication

Relative temperature scale is successfully used all over the world for the quantitative analysis of thermal asymmetry in the diagnosis of breast tumors, but the size of the area of interest on which the amplitude of thermo asymmetry depends is also not standardized [2]. An example of quantitative processing of thermal data in a relative temperature scale can be a measurement of the skin temperature difference in the projection of the diseased organ and the temperature of the "adjacent healthy" regions [3]. This approach seems to the authors incorrectly both methodologically (the sizes of the "sick" and "healthy" regions and the distance between them are not specified), and informatively (for example, any neoplasm has a region of adjacent tissues with own changing anomalous hyperthermal field). At the thermal imaging examination of the patient during treatment, the authors propose normalizing the current values of the relative temperature in the area of interest to the corresponding values of the thermal field measured before treatment start in order to exclude residual anomalous fields caused by previous treatment (in our case, residual hyperthermia in some patients after chemotherapy). Also, the authors consider incorrect to measure the temperature of one pixel of the image and so use averaged temperatures over the region of interest and over the reference region. With this approach, the correct choice of the sizes and locations both for reference region and area of interest is one of the important tasks of the development the procedure of thermal measurement and data processing [4].

Formulating the purpose of the article

The purpose of this article is briefly description of the simple approach to the quantitative processing of temperature data obtained at the thermal imaging examination of oncological patients during RT. The main goal of whole study is the development a thermal imaging methods of thermal monitoring and predicting the level of side reactions caused by irradiation.

Presenting the main material

19 male patients aged 44÷68 with cancer of head/neck location (predominantly oropharynx), being treated with identical RT regimen at the Kharkov Regional Clinical Cancer Center (Ukraine), were under study. Each patient was imaged for not less than 5 times: prior to RT start (infrared (IR) session #0) and weekly before each subsequent cycle of RT (IR sessions #1...4). Prior to each thermal imaging session, the current level of oral mucositis (OM – one of the local toxicity kind caused by RT, and means inflammation of the mucosa) was estimated by another (clinical) method [5].

The original thermal imaging system developed in B.I. Verkin Institute for Low Temperature Physics and Engineering of NAS of Ukraine was utilized for temperature mapping. The device, based on uncooled (384x288) pixels focal-plane array, features spectral range of 8–14 micrometers, temperature sensitivity of 0.07 °C, spatial resolution of 1 milliradian, and an original software package specialized for medical application [6].

Taking into account the results of [4], the area (5x2) cm^2 in the outer surface of the lower lip was chosen as the area of interest (Fig. 1) because:

- this area is nearest projection of the mucosa to the skin;
- this area is not subjected to radiation, therefore the temperature changes caused by OM, do not mix with the hyperthermia caused by radiation dermatitis (significant at used method of RT);
- according to the results of [1], the association between early temperature changes and subsequent severity of OM was statistically significant (P_{value} = 0.03) for this area.

A relative temperature scale was employed for quantitative analysis of the thermal images. The average temperature of the eyelid segments in the region of the nose bridge was used as the reference temperature (Fig. 1). It's a maximum temperature of the thermal field on the whole skin surface of healthy human. In addition, it correlates with the internal temperature, so changes in skin temperature caused by general patophysiological changes were excluded from the quantitative analysis [7]. The reference regions were not exposed to radiation.

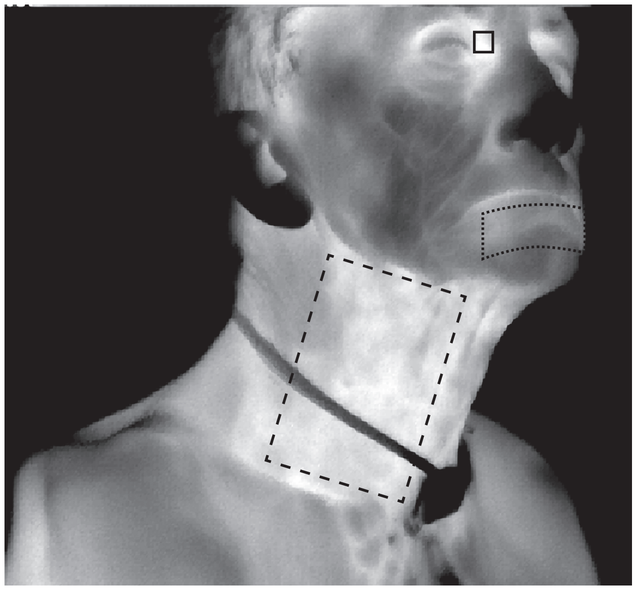

Fig. 1. Location and size of special areas on the patient's half-profile thermogram: (1x1) cm^2 square near eyes — reference regions; (5x2) cm^2 a rectangle on outer surface of the lower lip – area of interest, and (8x12) cm^2 a rectangle on the neck – area of irradiation.

In according with the previous results [4], averaged relative temperature measured on each IR session was normalized to the corresponding baseline value in the IR session #0. Thus, for each patient the following values were calculated:

$$\Delta T_i = \Delta(T_{ave})_i - \Delta(T_{ave})_0$$
$$\Delta(T_{ave})_i = (T_{ave})_i - (T_{ref})_i$$
$$\Delta(T_{ave})_0 = (T_{ave})_0 - (T_{ref})_0 ,$$

where $(T_{ave})_i$ and $(T_{ref})_i$ are the temperatures averaged over the area of interest and reference area, respectively, in the IR session #i; $\Delta(T_{ave})_i$ is the relative average temperature in the IR session #i; ΔT_i is the relative average temperature in the IR session #i normalized to the corresponding temperature in the IR session #0.

In the patients under study, a correlation between the current normalized relative temperatures in the area of interest and the corresponding OM grades was found: correlation coefficients $R\ (\Delta T_i\text{: OM}_i)_{1...19}$ = = 0.775; 0.756; 0.787 and 0.807 in IR sessions #1...4. This result is positive for the assumption about using thermal imaging method for quantitative monitoring of the current mucositis. Moreover, we observed a clear association between the temperature rise in the IR session #1 (accumulated dose ≈ 10 Gy) and both maximum and average mucositis grades during RT, for example $R\ (\Delta T_1\text{: OM}_{ave})_{1...19} = 0.817$. The first of the two seems especially important because the attainment of unforeseen severity mucositis OM > 3 leads to the necessity of providing aggressive supportive care or interrupting RT. To confirm the presence of the observed connection, Spearman's nonparametric correlation was applied for samples of ΔT_1 and OM_{max}. We obtained Spearman correlation coefficient $r = 0.76$ and estimated its statistical significance $T_{kp} = 0.33$, $T_{kp} < r$, that confirms a strong and direct association between the normalized temperatures in the area of interest in the IR session #1 and values of OM_{max} up to which mucositis could develop afterwards.

Based on these results, a prediction method was formulated, namely:

at $\Delta T_1 > 0.9$ °C, the development of mucositis is expected up to $OM_{max} > 3$;

at $\Delta T_1 \leqslant 0.9$ °C, the development of the severe mucositis grade is not expected:

$OM_{max} \leqslant 3$.

To estimate the informativity and resolution of the proposed prediction method, we organize the available data in the conjugation table (Table), which shows the correlation between the errors of type 1 and type 2.

The contingency to assess the informativity of the diagnostic test

Number patients with: / Normalized thermal parameters	The presence of high levels of mucositis (OM > 3)	Lack of high level of mucositis (OM ≤ 3)
$\Delta T \geqslant 0.9$ °C	4 (a)	3 (c)
$\Delta T < 0.9$ °C	1 (b)	11 (d)
Total	5	14

As a result, the following parameters were calculated:

- sensitivity of the method = 0.8;
- specificity = 0.78;
- accuracy = 0.79.

Based on this values, a ROC (receiver operating characteristic) curve, that demonstrates the number of correctly predicted existing $OM_{max} > 3$, vs. the number of incorrectly predicted non-existent $OM_{max} > 3$, was constructed [8], (Fig. 2).

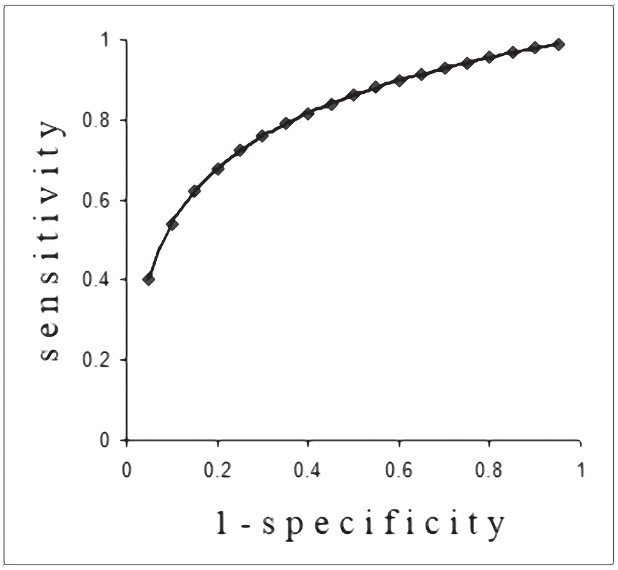

Fig. 2. Receiver Operating Characteristic (ROC) curve

The area under the characteristic curve (Area Under Curve, AUC = 0.79) demonstrates "good quality" of the method. Unfortunately, the number of patients under study was limited by the Project timeframe, so sufficient statistical power of the analysis was not provided. To confirm the evidence of this method, further research is needed.

Conclusions

The correlation coefficients $R = (0.76 \div 0.81)$ between the thermal and clinical parameters as well as the index "good quality" (AUC = 0.79) of prognosis method have been obtained using proposed approach for measuring and quantifying the dynamical temperature field on the human skin surface. Based on these algorithms the thermal imaging methods can be used both for clinical monitoring of current level of OM and for early prediction the maximal value of OM for each patient.

The results of the study in more detail are published in [9] (in Russian).

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Методика вимірювань динаміки температурних полів людини

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Анотація

Відсутність встановленого стандарту як для дистанційного вимірювання динаміки температурних полів на поверхні шкіри людини, так і для відповідної кількісної обробки даних є однією з серйозних причин, які обмежують використання унікального неінвазивного термографічного методу в клінічній медицині. Ми запропонували оригінальну методику вимірювання та кількісного аналізу масиву температурних даних, отриманих протягом термографічного обстеження групи онкологічних пацієнтів під час променевої терапії (ПТ). Ця методика призначена для кількісного контролю поточного рівня локального побічного ефекту (орального мукозиту – ОМ), який виникає у пацієнтів при отриманні ними ПТ, а також для прогнозування на ранній стадії ПТ індивідуального рівня "переносимості" опромінювання пацієнтом. Через специфіку терморегуляції людини для кількісної оцінки інтенсивності випромінювання шкіри було використано індивідуальну для кожного пацієнта відносну шкалу температури. Середня температура поверхні певної ділянки шкіри була обрана як еталонна температура, а температурне поле в зоні інтересу кожного пацієнта до початку ПТ використовувалося при розрахунках як базове. Точність вимірювання відносної температури при такому підході обмежувалася температурною чутливістю термографічної системи $\Delta T \approx \pm$ 0,07 °C. Було отримано коефіцієнти кореляції R = (0,76 ÷ 0,81) між тепловими та клінічними параметрами, а також показник "хороша якість" (AUC = 0,79) методу прогнозування. Ці результати вказують на можливість використання запропонованого підходу для вимірювання та обробки даних при термографічному моніторингу поточного рівня ОМ і для раннього прогнозування максимального рівня ОМ для кожного пацієнта. Автори відзначають необхідність продовження досліджень для збільшення статистичної потужності результатів.

Ключові слова: інфрачервона термографія, дистанційне вимірювання температури, медицина.

Методика измерений динамики температурных полей человека

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Аннотация

Отсутствие установленного стандарта для дистанционного измерения динамики температурных полей на поверхности кожи человека и для соответствующей количественной обработки данных является одной из серьезных причин, ограничивающих использование уникального неинвазивного термографического метода в клинической медицине. Мы предложили оригинальную методику измерения и количественного анализа массива температурных данных, полученных при термографическом обследовании группы онкологических пациентов во время лучевой терапии (ЛТ). Эта методика предназначена для количественного контроля текущего уровня локального побочного эффекта (орального мукозита – ОМ), который возникает у пациентов при прохождении ими ЛТ, а также для прогнозирования на ранней стадии ЛТ индивидуального уровня "переносимости" облучения пациентом. В силу специфики терморегуляции человека для количественной оценки интенсивности излучения кожи была использована индивидуальная для каждого пациента относительная шкала температуры. Средняя температура поверхности определенного участка кожи была выбрана как эталонная температура, а температурное поле в зоне интереса каждого пациента до начала ЛТ использовалось при расчетах в качестве базового. Точность измерения относительной температуры при таком подходе ограничивалась температурной чувствительностью термографической системы $\Delta T \approx \pm$ 0,07 °C. Были получены коэффициенты корреляции R = (0,76 ÷ 0,81) между тепловыми и клиническими параметрами, а также показатель "хорошее качество" (AUC = 0,79) метода прогнозирования. Эти результаты указывают на возможность использования предложенного подхода для измерения и обработки данных при термографическом контроле текущего уровня ОМ и для раннего прогнозирования максимального уровня ОМ для каждого пациента. Авторы отмечают необходимость продолжения исследований для увеличения статистической мощности результатов.

Ключевые слова: инфракрасное тепловое изображение, измерение температуры, медицина.

References

1. Diakides N.A., Bronzino J.D. Medical Infrared Imaging. CRC Press, 2007. 448 p.
2. Ng Y.K., Ung L.N., Ng F.C., Sim S.J. Statistical analysis of healthy and malignant breast thermography. *Journal of Medical Engineering and Technology,* 2001, no. 25(6), pp. 253–263.
3. Rozenfeld L.G., Samohin A.V., Venger E.F. et al. Distantsionnaya infrakrasnaya termografiya kak sovremennyiy neinvazivnyiy metod diagnostici zabolevaniy [Remote infrared thermography as a modern non-invasive method for disease diagnostics]. *Ukrayinskyi medychnyi chasopys – Ukrainian Medical Journal,* 2008, no. 6. 68 p. (in Russian).
4. Cohen E.E., Ahmed O., Kocherginsky M. et al. Study of Functional Infrared Imaging for Early Detection of Mucositis in Locally Advanced Head and Neck Cancer Treated With Chemoradiotherapy. *Oral Oncology,* 2013, no. 49 (10), pp. 1025–1031.
5. Mucositis grading scales WHO. Available at: http://www.gelclair.net/Institutional.aspx? Pagina=239&SM=230&Lingua=EN (accessed 15 April 2018).
6. Gordiyenko E., Glushchuk N., Pushkar Yu. et al. A Multi-element Thermal Imaging System Based on an Uncooled Bolometric Array. *Instruments and Experimental Techniques,* 2012, no. 55(4), pp. 494–497.
7. Ivanitskii G.R., Deev A.A., Krest'eva I.B. et al. Characteristics of Temperature Distributions around the Eyes. *Doklady Biological Sciences – Reports of Biological Sciences,* 2004, no. 398, pp. 367–372.
8. Software packages "VassarStats". Available at: http://www.vassarstats.net and www.graphpad.com (accessed 20 May 2018).
9. Shustakova G., Fomenko Yu., Gordiyenko E. et al. Ispolzovanie termograficheskogo metoda dlya kontrolya i prognozirovaniya urovnya mukozita pri luchevoy terapii opuholey golovy/shei [Application of Infrared Thermal Imaging for Monitoring and prediction of Mucositis Grade in the Course of Radiotherapy of Head/Neck Tumors]. *Ukrainskiy radiologicheskiy zhurnal – Ukrainian Journal of Radiology,* 2015, no. 23(3), pp. 30–37 (in Russian).