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IR imaging: identification of regional metastasis

G.V. Shustakova, N.N. Kolotilov, N.I. Glushchuk, E.Yu. Gordiyenko, L.G. Miroshnichenko, Yu.V. Fomenko, T.B. Shustakova

B.Verkin Institute for Low Temperature Physics and Engineering (LTPE) of NAS of Ukraine
Institute of Nuclear Medicine and Diagnostic Radiology of NAMS of Ukraine
Kharkov Regional Clinical Oncology Center
H.S. Skovoroda Kharkov National Pedagogical University

Introduction

Nowadays, medical infrared imaging systems based on multielement focal-plane array (FPA) are characterized by a unique temperature sensitivity (a few hundredths of a degree) and spatial resolution (less then one milliradian). Due to these parameters, the quantitative analysis of the smallest changes in the external temperature distribution on the skin surface of biological objects is available. Nevertheless, a deep understanding and thorough analysis of pathophysiological internal processes are necessary to correct interpretation of obtained thermal images [2, 3].

Back in the 70s of the last century the "phenomenon of flame" [4] was discovered: hyperthermal cords extending from hyperthermal center of primary malignant tumor towards the nearest lymph node (LN) signaled the beginning of lymphatic metastasis. This prognostically unfavorable symptom was observed in patients with various nosological forms of tumor, its stage and location, both prior the treatment start and during the radiation therapy (RT).

LN is the peripheral organ of the lymphatic system that performs the function of a biological filter for lymph which is coming from the organs and body parts. LNs are round, oval or bean-shaped (rarely band-shaped) formations with the sizes from 0.5 to 50 mm and more. LNs normally are located along the lymphatic vessels, usually as clusters of up to ten ones, near the blood vessels, often - near the large veins.

Since 1977, the concept of the *sentinel (signal)* LN is known, according to which the outflow of lymph from the tumor focus presumably is carried to it primarily [1]. This LN is a barrier to tumor cells, therefore is affected by metastasis first. For example, at the breast cancer, the signal LN is usually one of the axillary LNs [7].

The detection of the way of lymphatic metastasis is important for staging of the tumor process, planning of surgery, marking the region of RT irradiation, searching of undiagnosed primary tumor [4, 6, 7]. The method of indirect contrasting lymphangiography has been proposed for sentinel LNs searching [6, 7]

Generally accepted methods of medical visualization (ultrasound, CT, MRI, radionuclide diagnostics) are not able to identify the presence or absence of metastasis in LNs in the early stages [7].

The sole reference method of diagnosis of lymphatic metastasis is a biopsy of the *signal* LN - a diagnostic surgery with removing a piece of LN tissue for histological verification and assessment of the prevalence of tumor process.

The biopsy can be performed instead of the more time-consuming LN dissection. If the cancer is diagnosed at the dissection of the signal LN, surgical removal of other LNs is necessary.

Purpose – to study the thermal topography of the patient's skin in the projections of the tumor and regional LNs during RT.

Materials and methods

70 patients with various cancer type, stage and location including larynx, tonsils, tongue – 25 patients, skin – 10, breast – 15, gastrointestinal tract, lungs, bones – 20, were examined by IR imaging method prior to treatment start and weekly during RT [8, 9].

The study was carried out by IR imaging system developed in LTPE of NAS of Ukraine [5].

The system is based on FPA of uncooled (384 x 288) microbolometers. The base parameters of the system are: spectral range of 8-14 micrometers, temperature sensitivity of 0.06 ^{0}C, spatial resolution of 1 milliradian. The system features the original software specialized for medical application.

Results and discussion

Metastasis of the right hip joint and ilium at undiagnosed primary tumor, $T_xN_xM_1$ (Fig. 1). Numerous hyperthermal cords with the temperature several degrees above the temperature of the surrounding skin are observed on the thermal image of patient's pelvis. Hyperthermal region (T_{max} = 38.4 ^{0}C) in the projection of metastasis is associated with hyperthermal area in the projection of the sacrum and lumbar spine by hyperthermal cord.

The patient was assigned to RT by fractionation method to the region of projection of metastasis and to the symmetric region, the total dose (TD) ≈ 40 Gy, the daily dose (DD) ≈ 2 Gy. Three focuses of hyperthermia with abnormally high temperatures of the skin, T_{max} = 38.0 ^{0}C, 37.9 ^{0}C and 37.3 ^{0}C, were detected at a detailed study of the area in the projection of the sacrum and lumbar spine (Fig. 2). Fig. 2c displays temperature profiles in the direction perpendicular to hyperthermal cord connecting the presumed primary tumor and the metastasis. Small hyperthermia ($\Delta T \approx 0{,}7$ ^{0}C) due to radiation dermatitis (Fig. 2a, b, c) is observed after 10 RT sessions in the field of irradiation.

Comparison of both thermal images and temperature profiles prior to treatment start and after 10 sessions of RT shows that the structure and the temperature distribution of the initial foci of hyperthermia and hyperthermia actual strands have not changed much because of RT except for a slight redistribution in the temperature of the skin over the sacrum.

Metastasis of cancer in the neck right LNs from the undiagnosed primary tumor, $T_xN_xM_1$, planocellular non-keratinizing cancer; the status: after polychemotherapy (Fig.3). Fragments of the frontal thermal images of the patient with observed thermal cords emanating from the region of the affected cervical lymph nodes, prior to RT start and after a full course of RT, are demonstrated in Fig.3.

The differences between the average temperature in the area with thermal cords, and the average temperature in symmetrical contralateral intact area (both areas are indicated by white dotted rectangles) were: $\Delta T \approx 2.2^0$C before the start of RT and $\Delta T \approx 2.5$ ^{0}C after the end of RT. These areas were not irradiated (radiation dermatitis is absent). It should be noted that the number and position of the cords have barely changed owing to RT.

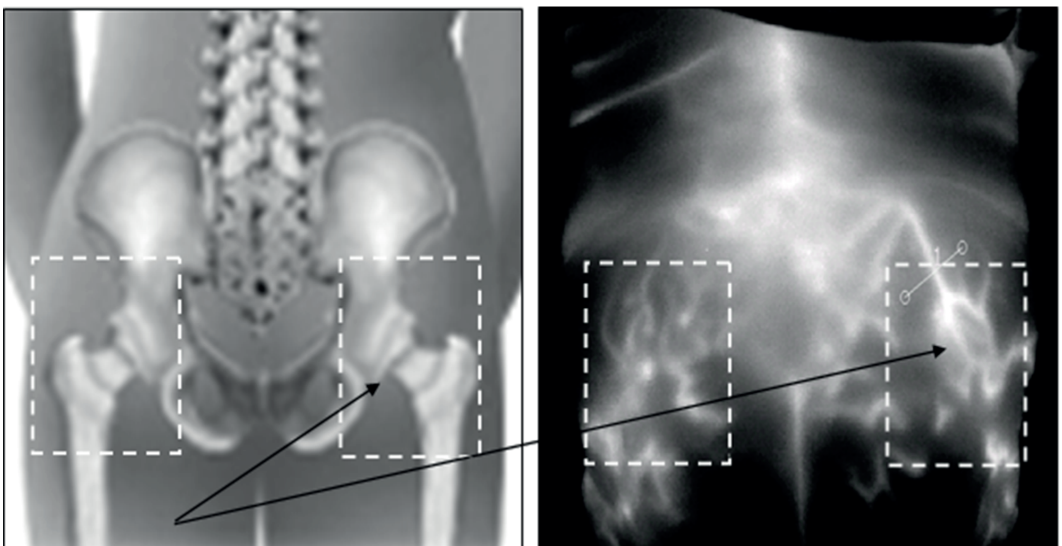


Fig. 1. *Patient A., 65 years old. X-ray of the pelvis bones and the thermal image of the skin surface in the same position. Rectangles - irradiation field (16x16) cm^2, arrows - localization of metastasis and its projection on the skin.*

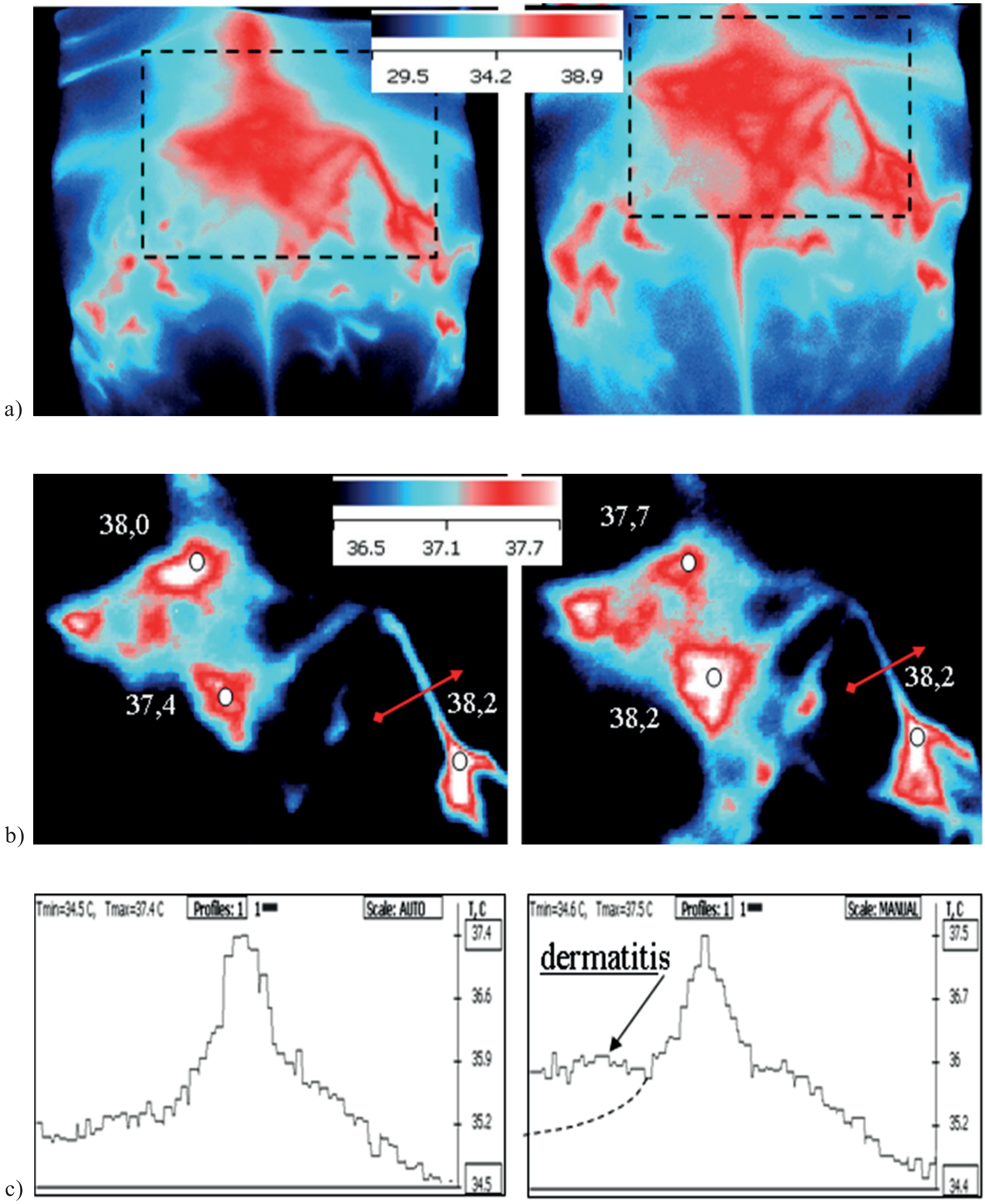


Fig. 2. *Patient A. Dynamics of the termotopografy during radiotherapy: a) thermal images in a single temperature scale, b) fragments of the thermal images, c) the temperature profiles (indicated on fig. 2b of red arrows) across hyperthermal cord connecting the projection of the metastasis and the projection of a possible primary foci of tumor growth.*

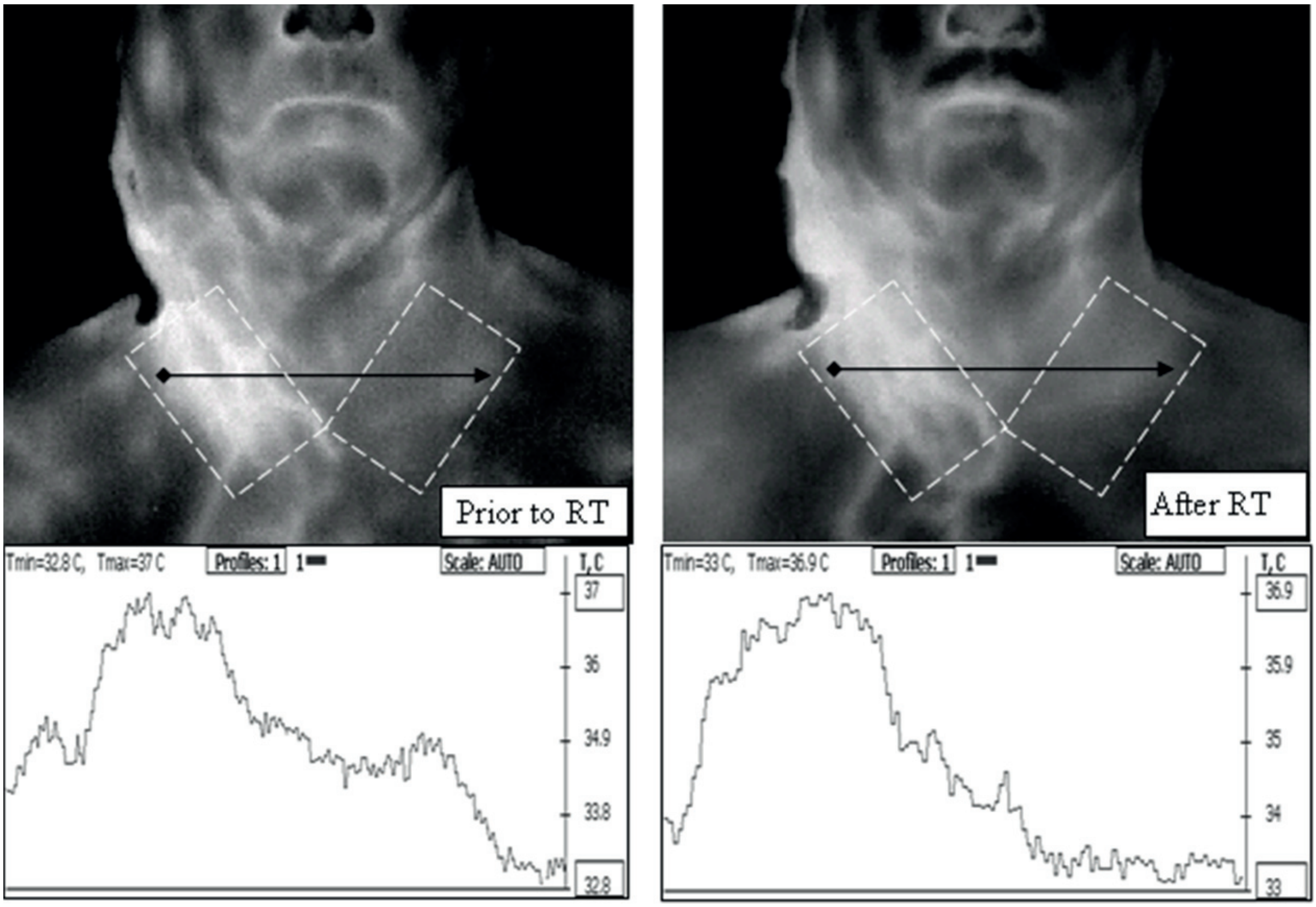


Fig. 3. *Patient B., 68 years old. Thermal images of the thermal cords emanating from the affected cervical LN ($T_xN_xM_1$) prior to and after the full course of RT are shown. Under images are shown the temperature profiles (along the black arrows on the images). The fields for quantitative analysis are marked by the white rectangles.*

Only a small positive dynamics has been noted as a result of RT due to low radiosensitivity of the tumor and large sizes of the lesion area. Observation of the thermal cords on the skin, which are the thermal prints of the ways of lymph outflow, revealed the immutability of their number and position during RT.

It should be noted that the similar stability of hyperthermal cords was also observed in the case of significant positive dynamics during the treatment.

Inguinal non-Hodgkin's MALT-lymphoma in III-B stage (Fig. 4). Two hyperthermal cords with temperature exceeding the temperature of the surrounding skin by $\Delta T \geq 1.5\ ^0C$ are observed in the thermal images. The cords connect the affected and intact inguinal LN.

After a course of RT (TD ≈ 36 Gy), the tumor diameter has reduced from 18 cm to 10 cm [9] but the cords temperature remained unchanged, as can be seen on the temperature profiles (in the same temperature scale) across the cords prior and after RT.

Examples of the thermal images with hyperthermal cords with temperature exceeding the temperature of surrounding skin by more than 1.5 ^0C (Fig. 5) are: squamous cell carcinoma of the larynx $T_3N_0M_0$, post tracheostomy, after the end of RT (Fig. 5a); squamous cell carcinoma of the tongue $T_3N_0M_0$ (Fig. 5b); cancer of the forehead skin ($T_3N_0M_0$) and squamous cell carcinoma of the upper eyelid skin ($T_1N_0M_0$), 2 weeks after the end of RT (Fig. 5c).

The superfine hypothermal "hairs" with a temperature difference between the "hairs" and surrounding skin $\Delta T \approx -0,5\ ^0C$ (Fig 5c) presumably are the skin projections of the expanded capillaries in a state of stasis and spasm. The transverse temperature profiles for each thermal image help to estimate the temperature gradient of the corresponding thermal cords.

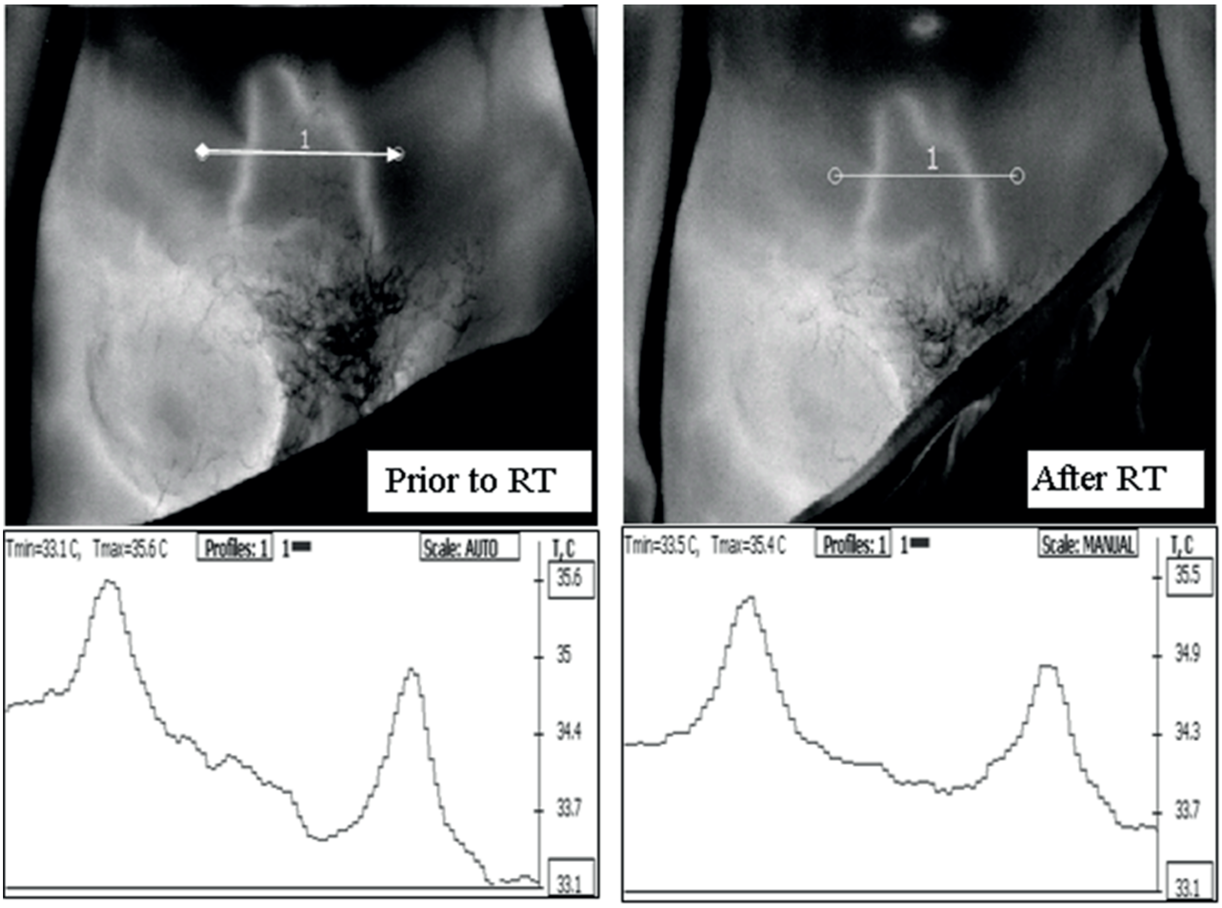
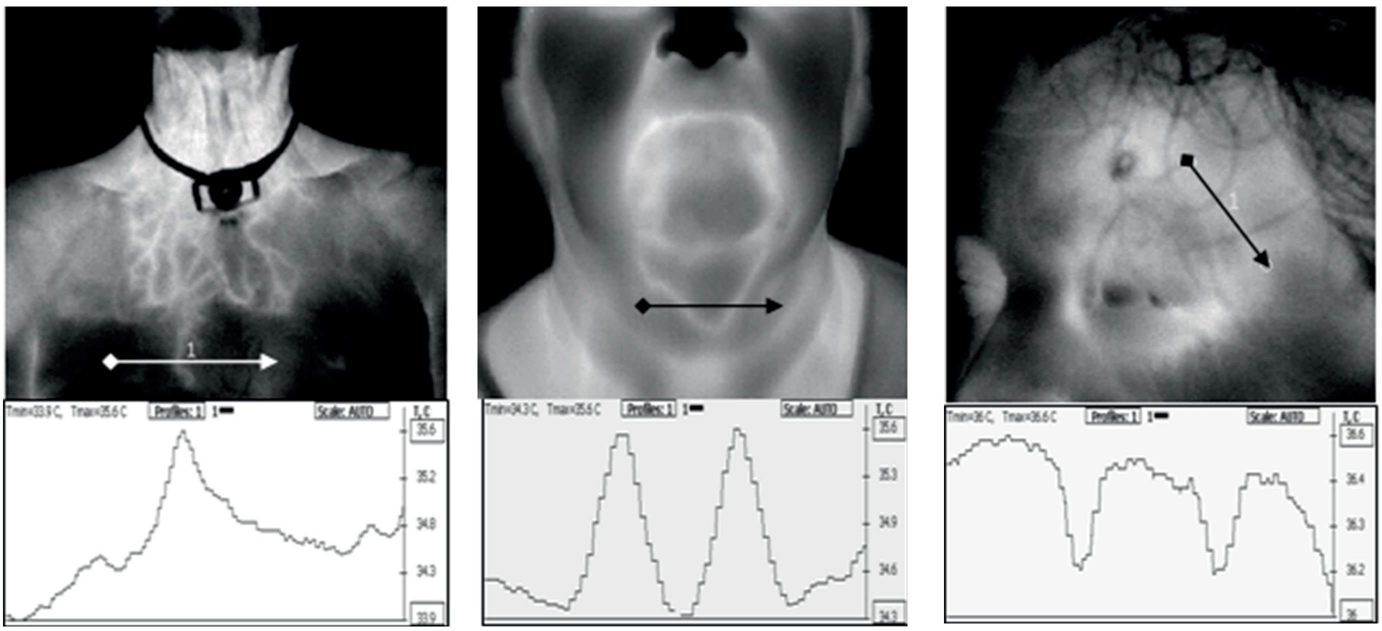


Fig. 4. *Patient B., 52 years old. The thermal images and corresponding temperature profiles in a single temperature scale demonstrate the stability of the hyperthermal cords during RT.*



a) b) c)

Fig. 5. *Thermal images of the hyper- and hypothermal cords: a) cancer of the larynx $T_3N_0M_0$ after RT; b) tongue cancer $T_3N_0M_0$ prior to RT; c) cancer $T_3N_0M_0$ of the forehead skin and cancer $T_1N_0M_0$ of the upper eyelid skin after RT.*

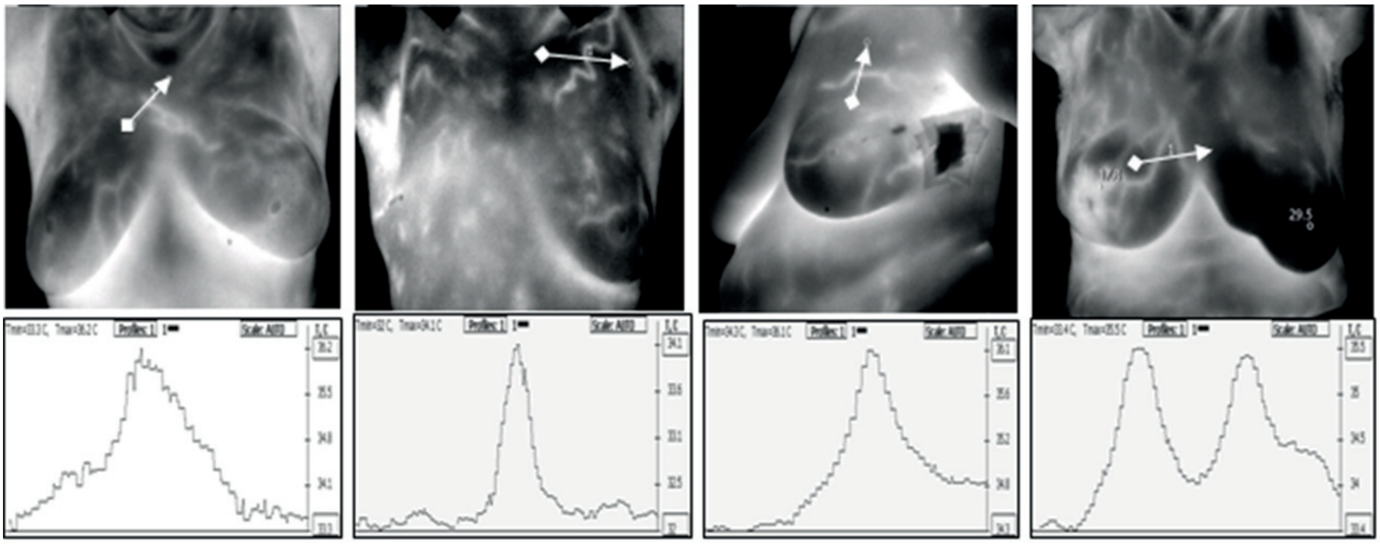


Fig. 6. Thermal images of the thermal cords on the skin of patients with malignant tumors of the breast and axillary LNs.

Most often hyperthermal cords may be observed in the thermal images of the malignant tumors of breast (Fig. 6).

Conclusion

Within the concept of sentinel LN, thermal topography of the skin in the projections of the tumor and regional LNs have been studied during RT. Using noninvasive thermal imaging method, lymphatic metastasis can be identified by hyperthermal cords on the skin connecting the projections of the tumor and regional sentinel LN. Hyperthermal cords correspond to lymph or blood vessels; their identification and adequate interpretation may facilitate the identification of the sentinel LN, primary foci of tumor growth. Most often hyperthermal cords are observed in the thermal images of the malignant tumors of breast. Observations of the dynamics of the thermal cords on skin during RT showed that their thermal characteristics and location remained virtually unchanged as a result of irradiation, even if there was a significant regression of the tumor itself.

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G.V. Shustakova, N.N. Kolotilov,
N.I. Glushchuk, E.Yu. Gordiyenko,
L.G. Miroshnichenko,
Yu.V. Fomenko, T.B. Shustakova

Purpose – to study the thermal topography of skin in the projections of the tumor and regional lymphatic nodes during radiotherapy.

Materials and methods. 70 patients with various cancer type, stage and location were examined by IR imaging system prior to treatment start and weekly during radiotherapy.

Conclusion. Using noninvasive IR imaging method, lymphatic metastasis can be identified by thermal cords on the skin connecting the projections of the tumor and regional sentinel lymph node. Adequate interpretation of the thermal cords may facilitate the identification of the sentinel LN, primary foci of tumor growth. Observations of the dynamics of thermal cords during RT showed invariability of their position and thermal characteristics at irradiation, even if there was a significant regression of the tumor itself.

Keywords: Infrared thermal imaging, radiotherapy, lymphatic metastasis.

ДИСТАНЦІЙНА ІНФРАЧЕРВОНА ТЕРМОГРАФІЯ: ІДЕНТИФІКАЦІЯ РЕГІОНАЛЬНОГО МЕТАСТАЗУВАННЯ

Г.В. Шустакова, М.М. Колотилов,
М.І.Глущук, Е.Ю. Гордієнко,
Л.Г. Мірошниченко, Ю.В. Фоменко,
Т.Б. Шустакова

Мета – вивчити термотопографію шкіряних покривів в проекції пухлини і регіональних лімфатичних вузлів в процесі променевої терапії.

Матеріали та методи. 70 пацієнтів з різними стадіями і локалізаціями пухлин були термографовані до початку лікування і щотижня протягом променевої терапії.

Висновки. Лімфатичне метастазування може бути виявлено неінвазивним тепловізійним методом по тепловим «тяжам» на шкірі, які поєднують проекції пухлини і регіонального сторожового лімфатичного вузла. Виявлення і правильна інтерпретація теплових тяжів дозволяє ідентифікувати дозорні лімфовузли і первинні осередки зростання пухлини. Спостереження за динамікою теплових тяжів внаслідок опромінення показали відсутність змін їх локалізації і теплових характеристик, навіть при значній регресії самої пухлини.

Ключові слова: Термографія, променева терапія, лімфатичне метастазування.

ДИСТАНЦИОННАЯ ИНФРАКРАСНАЯ ТЕРМОГРАФИЯ: ИДЕНТИФИКАЦИЯ РЕГИОНАЛЬНОГО МЕТАСТАЗИРОВАНИЯ

Г.В. Шустакова, Н.Н. Колотилов,
Н.И.Глущук, Э.Ю. Гордиенко,
Л.Г. Мирошниченко, Ю.В. Фоменко,
Т.Б. Шустакова

Цель – изучить термотопографию кожных покровов в проекции опухоли и регионарных лимфатических узлов в процессе лучевой терапии.

Материалы и методы. 70 пациентов с различными стадиями и локализациями опухолей были термографированы до начала лечения и еженедельно во время лучевой терапии.

Выводы. Лимфатическое метастазирование может быть выявлено неинвазивным тепловизионным методом по тепловым «тяжам» на коже, соединяющим проекции опухоли и регионального сторожевого лимфатического узла. Выявление и правильная интерпретация тепловых тяжей позволяет идентифицировать сторожевые лимфоузлы и первичные очаги роста опухоли. Наблюдения за динамикой тепловых тяжей во процессе облучения показали отсутствие изменений их положения и тепловых характеристик в даже при значительной регрессии самой опухоли.

Ключевые слова: Тепловидение, лучевая терапия, лимфатическое метастазирования.