The use of thermography in radiobiological dosimetry

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SUMMARY. Thermographic techniques have been applied to the detection of radiation-induced injury. In none of ten patients who received a nominal standard dose (N. S. D.) under 1000 rads was skin temperature in excess of 1°C noted in the irradiated area as compared to the symmetric unirradiated region of the body. In patients with an N. S. D. of 1453 and 1292 rads there occurred thermal asymmetry in the absence of cutaneous erythema. Thermography detects irradiation injury to skin with doses from ^{60}Co of this magnitude prior to the appearance of skin erythema.

Key words: radiation injury, thermography, skin, nominal standard dose.

An accurate and rapidly available biologic dosimetric system for measuring absorbed radiation doses is not yet at hand. Biologic indicators of radiation injury may not always have the same degree of precision as that available for physical dosimeters [1]. However, the former will be available with greater rapidity to the clinician who requires estimates of the absorbed dose to establish the degree and extent of radiation injury following a radiation accident.

The effect of radiation on the skin was historically the first biological indicator employed [15], and the skin erythema dose, or S.E.D., became the unit of measurement of absorbed radiation dose [10]. The dose effect is dependent on the area irradiated, the energy, quality, dose rate, fractionation, and depth dose of the radiation employed [9].

Infra-red thermography has been employed with some success in the diagnosis of numerous medical conditions [2, 3, 8, 11, 12]. Biophysical aspects of this technique have been reviewed elsewhere [6].

The purpose of this study has been to determine if thermography, a technique with sensitivity to temperature changes of fractions of a degree, would be an adequate radiobiological dosimetry technique in the evaluation of radiation accident victims.

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MATERIALS AND METHODS

Patients receiving cobalt-60 radiotherapy for a variety of malignant neoplasms were studied serially during the course of treatment within thirty minutes of termination of radiotherapy. Informed consent was obtained from each individual. These individuals were instructed to take no medication for 24 hours prior to the study. None had smoked a cigarette or ingested hot or cold beverages for 2 hours prior to thermography. Clothing was removed from the area of the body to be studied in a closed room with temperature maintained at 23±1°C. A twenty minute period was allowed for thermal equilibrium [6]. The patient lay supine or prone on a table during the study and the infra-red radiation emitted by his body was reflected into a Barnes/Bofors Model M-101 Medical Thermograph by a front-silvered mirror angled above him. The radiation was converted to an electromagnetic signal which produced visible light photographed by a Polaroid camera.

Symmetric areas on each patient's body one inch square were carefully measured from the midline to correspond exactly to the irradiated region and marked with indelible ink. Thermograms were first obtained from the skin 20 minutes after the marking process, and then slender pieces of aluminum foil were overlayed on the ink marks delineating each area. The margins of these symmetrical regions appeared as dark lines on this second thermogram because of the low emissivity of the shiny surface. The outlined areas on the second thermogram were initially transferred to the first picture by superimposing the Polaroid films and punching pin holes along the border of the outlined area. It was subsequently determined during these experiments that the thin boundaries of foil did not change the temperature of the enclosed skin.

A pre-calibrated thermal gray scale, containing squares of known constant temperature from 29° through 38°C, was positioned to appear on each scan. The temperature of each square was unchanged on recalibration by the manufacturer, confirming the validity of using this scale for measuring heat emission.

Densitometer readings were obtained from the thermal gray scale and plotted against the temperature reading of this scale. The resultant curve was used to obtain the skin temperatures of the two sides of the body being compared, employing the densitometer readings of the one inch square areas seen on the thermograph. Two densitometers were employed but gave indentical readings for each picture. A new temperature-densitometry curve was plotted for each thermogram examined. Maximum error attributable to the densitometer, obtained from multiple readings of the same areas of selected thermograms was 0.133°C (mean + 2 s.d.). The thermography equipment which we employed had no intrathermogram drift according to the manufacturer.

Since patients were followed throughout their radiotherapy, the variables of number of fractions and total time relative to total dose made any simple summation of dose accumulated inaccurate. The concept of nominal standard dose (N.S.D.) was therefore employed to correlate the biologic effect of radiation dose with skin temperature [5]. The N.S.D. is employed as the best available estimate of the biologically equivalent single dose. The N.S.D. is that radiation dose which in one exposure would produce the same biological effect as the total fractionated dose (D): D=(N.S.D.) $(T^{0.11})$ $(N^{0.24})$ where D and (N.S.D.) are in rads, T is in days, and N is the number of the fractions.

From 10 healthy volunteers, each of whom had multiple thermograms taken on separate days, we established the normal upper limits (mean + 2 s.d.) of the difference between symmetric areas of the trunk as 1.0°C [14] corresponding well with the approximation of others [4, 6, 16].

RESULTS AND DISCUSSION

The thermographic determinations of the maximum difference (ΔT_{max}) of skin temperature between irradiated and the corresponding symmetric non-irradiated areas for each of our patients are listed in Table I, with the type of malignancy for which each was receiving cobalt-60 radiotherapy and the N.S.D. at which ΔT_{max} was achieved.

With nominal standard doses up to 962 rads we were unable to detect significant differences between irradiated and unirradiated sides with the thermograph. Patients with N.S.D. values of 1453 and 1292 rads did show definite thermal asymmetry post irradiation not present before. In none of these patients was there visible erythema or subjective discomfort in the irradiated area.

For several patients where sequential thermographic readings were available during therapy we attempted to determine the correlation between radiation dose and the difference in temperature between the irradiated and nonirradiated sides (ΔT). The correlations were generally low. We obtained occasional high correlations but they were both positive and negative. For example, one patient with a N.S.D. of 962 rads had a correlation of —0.87 for a region within his posterior lumbo-sacral area, while another patient with a N.S.D. of 946 rads, had a correlation of +0.73 for an area in his anterior upper abdomen. Hence, no correlation can be drawn between radiation doses and the ΔT at radiation doses up to 1000 rads. In all cases where the correlation appeared high, the ΔT did not exceed the upper limit for normal thermal asymmetry.

During the two month period of thermograph instrument availability only one patient was receiving 250 kVp x-ray therapy. Her N.S.D. was 1930 rads but the contribution of active superficial breast cancer to the abnormally high ΔT of 1.40 °C prevents any conclusion as to dose-response relationship of this quality of radiation and skin temperature.

In the only other published study employing thermography to detect temperature change during radiotherapy 16 patients receiving 5000 rads to the neck in 25 treatments over 5 weeks with ^{60}Co (final N.S.D. = 1570 rads by our calculation) all had an elevation of skin temperature eventually, but the time when the ΔT exceeded the normal 1°C of thermal asymmetry is not given for each patient [17], so that the threshold N.S.D. 's for causation of this phenomenon are unknown.

The threshold erythema dose, with an obvious ΔT for various qualities of radiation rises with the energy applied [7], and is given as 960 rads (single dose) for 1 MeV photons. Our human data are in agreement, with no significantly abnormal ΔT at doses under 1000 rads (N.S.D.). The patients whose skin temperature did rise significantly to exceed our normal values of thermal symmetry received N.S.D. 's of 1292 and 1453 rads, although visible cutaneous erythema, providing less subtle evidence of the abnormal ΔT, was not noted in either patient. Thus the erythema dose using the N.S.D. concept may be higher than with a single dose of radiation, but skin temperature elevation occurred only over the threshold noted above. The direct heat imparted to the skin from gamma rays, even assuming total absorption, is itself negligible and may be calculated as 2.39×10^{-6}°C per rad. Thus, with radiation doses under 1000 rads from cobalt-60 sophisticated thermographic equipment adds little to the upper limits of surface doses that one could estimate simply by visible erythema. However, radiation doses to the trunk from ^{60}Co well below those detectable with thermography will be apparent from early gastro-intestinal and hematologic changes [13] if given acutely. Nevertheless, thermography detected cutaneous thermal asymmetry not apparent from clinical findings at dose of 1292 and 1453 rads (N.S.D.) suggesting, along with a previously cited study [17], a role for thermography in determining the degree of cutaneous exposure in radiation accidents involving only part of the body, where systemic symptoms and signs will be absent or less obvious.

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