Thermography of the Human Body

Infrared-radiant energy provides new concepts and instrumentation for medical diagnosis.

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In 1800, Sir William Herschel (*1*), the great English astronomer, discovered that the sun's spectrum contained electromagnetic energy of longer wavelength than red light. This discovery of infrared radiation lay shrouded in doubt and controversy until 1840, when Sir J. F. W. Herschel (*2*), the son of the discoverer and himself a pioneer in the field of photography, succeeded in recording these invisible wavelengths on paper, forming what he called a "thermograph." Figure 1 shows a modern thermogram.

Today we know that every object whose temperature is above that of absolute zero emits infrared radiation, and, accordingly, if infrared cameras of sufficiently high sensitivity are available, thermograms may be made of any object of interest. These thermograms must not be confused with conventional infrared photographs, which may be taken with any conventional camera by using filters to remove visible light and film which has been sensitized to radiation of slightly longer wavelength than red light. For conventional infrared pictures the objects photographed generally must be illuminated by an extraneous source, and the contrasts obtained result largely from differences in the transmission and reflection power of the skin. Thermograms, on the contrary, may be taken in total darkness, since they are photographic reproductions of infrared radiations of longer wavelength emitted by the object itself when its temperature is above absolute zero. Thermograms are truly heat photographs and are capable of yielding quantitative information regarding the temperature of the object's surface.

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Generally speaking, systems in equilibrium tend to remain in equilibrium. If we upset a thermal equilibrium condition by heating a cup of coffee to a temperature above that of its surroundings, natural processes will cause it to cool off. Conversely, these same natural processes, in combination, cause a glass of iced coffee to warm up and to regain its thermal equilibrium. The earth, as it travels in its orbit around the sun, absorbs enormous quantities of heat and yet remains in thermal equilibrium with its celestial neighbors, with an average temperature of about 300°K. In these and in countless other cases where thermal equilibria are upset by the absorption of energy, the ability of the object to emit this absorbed energy is vital. It is fundamental to the existence of our world and to the maintenance of life itself, and it is because of this reciprocity between the absorption and the emission of energy that all objects emit infrared radiation as a function of their temperatures.

If an amount of electromagnetic energy E falls upon a partially transparent object, we may write $E = T + A + R$, where T, A, and R are the object's transmission, absorption, and reflection, respectively, expressed in percentages. If T approaches 100, the object is transparent; E passes through it without interaction, and $A + R$ approaches zero. In the case of an opaque object, $T = 0$ and $E = A + R$. If, at the same time, A is vanishingly small, the object is a good reflector or mirror and $E = R$. If, on the other hand, the surface of an opaque object is roughened or blackened, R becomes small, almost all of the energy is absorbed, and $E = A$. Absorption of energy causes the object's temperature to be increased, and in the absence of conduction or convection, this total increase must be got rid of through the process of emission. Since no totally transparent objects exist, a constant energy exchange, involving absorption and emission, takes place between every object and each of its line-of-sight neighbors. A good absorber is a good emitter, and it follows that highly transparent or highly reflective objects are poor emitters.

The emission of radiant energy is, therefore, a fundamental process of nature. It is known that the total energy emitted (E) by an object is proportional to its emissivity (ϵ) and to the fourth power of its absolute temperature (T^4). Thus, $E = \epsilon T^4$, where ϵ varies from 0 for a transparent object or a perfect mirror to 1 for a perfect absorber. Table 1 shows approximate values of ϵ for a few common materials. Objects whose absorption closely approaches 100 percent have emissivities almost equal to 1 and are referred to as "black bodies." Actually, no flat surface can be completely devoid of reflection, and thus a perfect "black body" can only exist as the inside of an opaque hollow enclosure. All other so-called "black bodies" only approach this ideal condition and should be referred to as "gray bodies." Emissivity is a direct function of absorption, and since absorption in turn is a function of wavelength, it follows that any given object may be transparent for one part of the spectrum and totally absorbing or "black" for other wavelengths. In considering emissivities, therefore, it is important that we know which part of the spectrum is under consideration. Glass, for example, which is transparent to visible light and opaque to long-wavelength infrared, is an excellent emitter of long-wavelength infrared.

If the energy emitted by a "black body" at a temperature T°K is examined spectrophotometrically, it is seen to consist of a broad band of wavelengths whose maximum of intensity, λ_{max}, lies at a value given by Wien's displacement law (*3*) as $\lambda_{max} = \sim 3000/T$, where λ is in microns and T is in degrees Kelvin. Figure 2 illustrates this relationship for a variety of familiar objects for which ϵ has been assumed to equal 1; in each of these cases it is the total energy, or the area under the curve, which varies in proportion to T^4. The displacement of λ_{max} toward shorter wavelengths with higher tem-

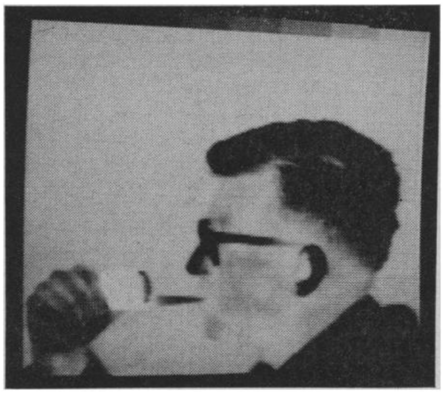


Fig. 1. A modern thermogram. Such a picture can be taken in total darkness. It is a quantitative recording of surface temperatures.

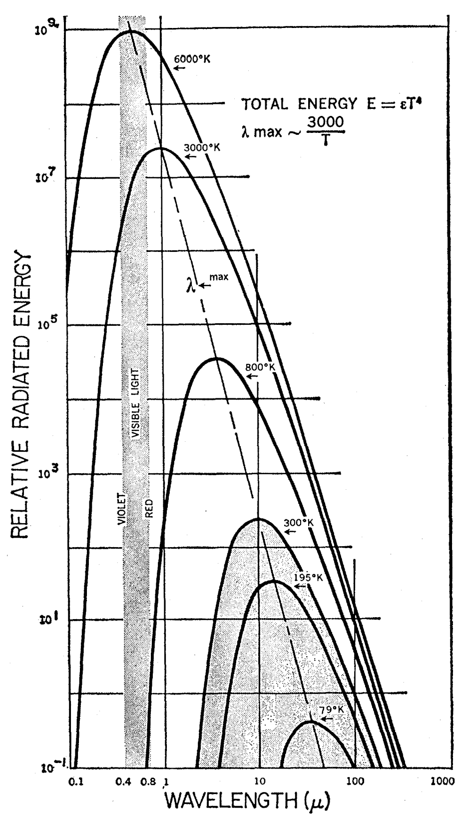
peratures is quite obvious, and from the 300°K curve it is clear that the self-emission from opaque objects whose temperatures are reasonably close to that of the earth lies essentially in the infrared, with a λ_{max} approximately equal to 10 microns. Such objects emit no visible light, and thus they cannot be seen unless they are illuminated by some external, much hotter, source. To instruments having infrared sensitivity, however, they all appear to be highly incandescent. *Incandescence* is defined as "glowing due to heat," and as the word is ordinarily used, the "glow" must be visible. From Fig. 2 it is clear that solids which are heated to 800°K or higher fulfill this condition and vary from red hot to white hot. We must stress the point, however, that all objects, regardless of their temperature, are infrared-incandescent. We ourselves are at all times glowing or emitting invisible "light"; we live in an infrared environment, where infrared is constantly being emitted, absorbed, and re-emitted by every object around us as these objects exchange radiant energy with their neighbors in their efforts to remain in thermal equilibrium.

During the past quarter century, interest in the field of infrared has increased tremendously. The capabilities of several infrared instruments have been widely recognized by industry, and today infrared spectrometers, for example, are being employed routinely in most analytical chemistry laboratories. Since all objects radiate infrared and since this emission may be utilized without the need for any active illuminating processes, infrared has contributed materially to the solution of many problems connected with national defense and the exploration of space. Among the developments to which it has contributed are the Sniperscope; the heat-seeking head of the Sidewinder missile; the horizon sensors used in the stabilization of spacecraft, such as that of the Project Mercury program; the temperature-measuring radiometers of the Tiros weather satellites, and the recent Venus probe, Mariner II. Today a wide assortment of sensitive infrared instruments are available for passive detection, temperature measurement, communication, viewing, and thermal photography.

Table 1. Approximate infrared emissivities (ϵ) for common materials at ambient temperatures.

Material	Emissivity
Human skin	0.99
Water, frost, rough ice	.98
Oil paints	.92–.97
Lamp black, soot, hard rubber	.95
Concrete, glass, red brick	.94
Paper, plaster, porcelain	.92
Plastics	.88–.91
Wool, silk, lumber	.78
Stainless steel, cast iron	.70–.74
Black loam, fire brick	.66–.69
Gravel, plowed field, granite	.28–.44
Polished cast iron, lead	.21–.28
Polished chrome, monel, stainless steel	.08
Mirrors, polished metals	.02–.03

A modern infrared camera described by Astheimer and Wormser (*4*) is shown schematically in Fig. 3. Infrared emitted by the source that is being thermographed falls upon a scanning mirror and is then focused upon a sensitive thermistor heat detector (*5*). By means of a rotating chopper mirror the



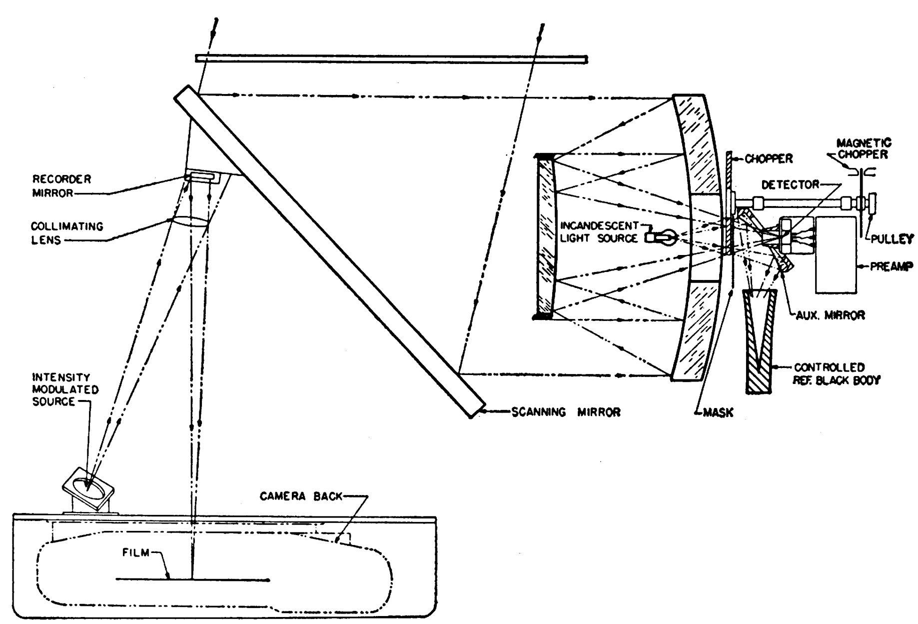


Fig. 2 (left). Black-body emission for familiar objects: (top to bottom) the sun, a 100-watt Tungsten lamp, a red-hot solid, the earth, dry ice, and liquid air.

Fig. 3 (above). Schematic diagram of an infrared camera. Infrared radiation entering from the top is converted to electrical signals and then to visible light and finally (lower left) is photographed.

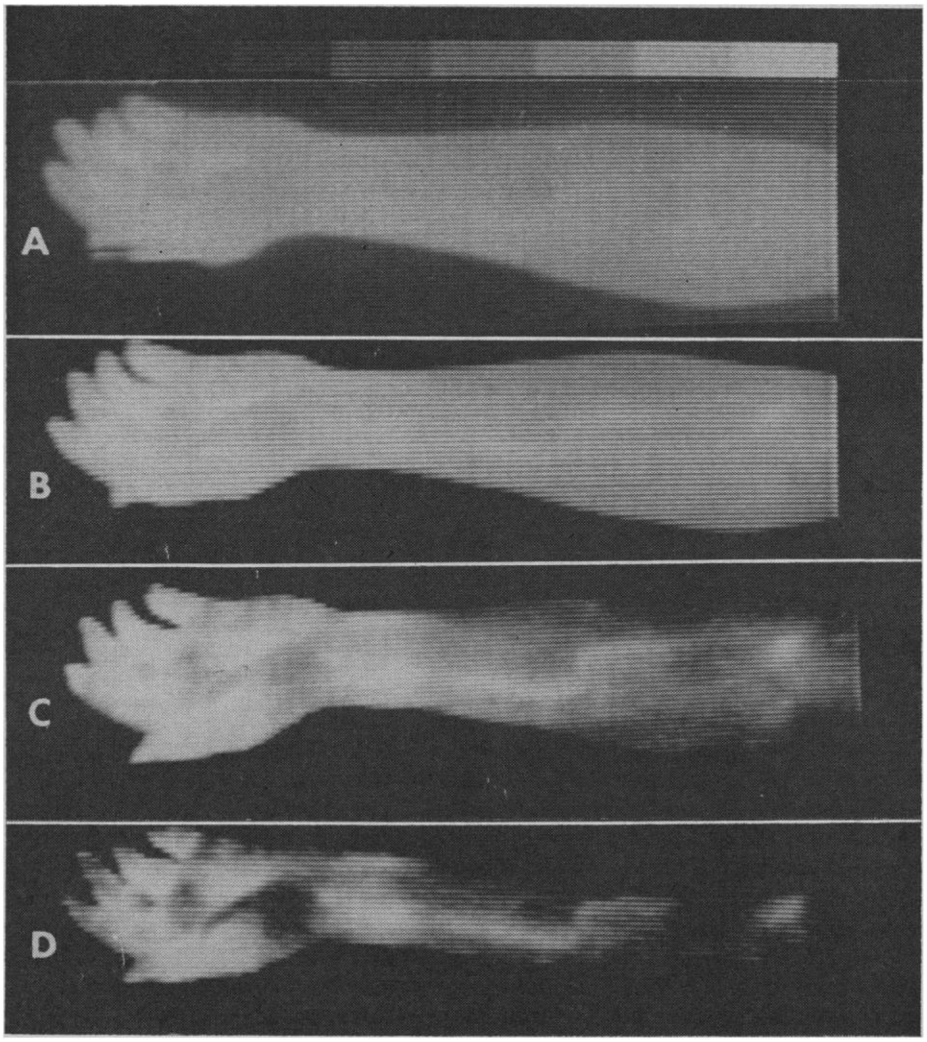
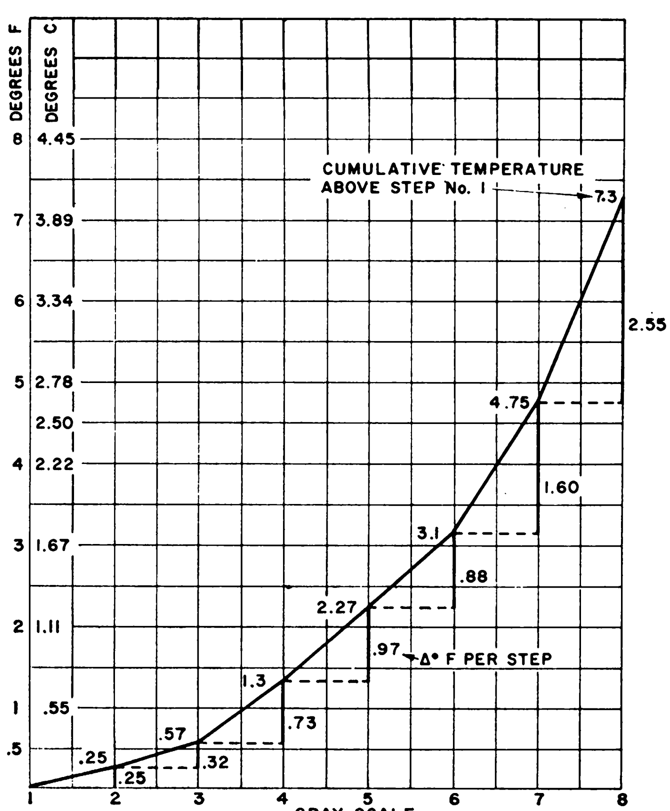


Fig. 4 (left). Thermograms of an arm, recorded at four different sensitivities. The temperature differences (ΔT) required to go from white (hot) to black (cold) are (top to bottom) 20°, 10°, 4°, and 2°C. Note the increasing contrast as the sensitivity is increased.

Fig. 5 (left below). Medium contrast temperature °F change vs. gray scale steps. A typical calibration curve for medium sensitivity (ΔT of 7°F required to go from white to black). Fig. 6 (right below). A comparison of infrared energy emitted by the human hand and by a black body at 32°C. [From Hardy (*7*)]

incoming energy is compared 200 times per second with the energy being emitted by an internal, constant-temperature reference black body. After the infrared radiation has been converted by the thermistor to an electrical signal, and after the signal has been suitably amplified and processed, the proportional output is used to control the intensity of a glow modulator tube which emits visible light. After being reflected from a mirror attached to the rear side of the scanning mirror, this visible light is focused upon the film of a camera. Thus, a perfectly registered, quantitative, two-dimensional record of the infrared emission from the object plane can be obtained directly from the density of the photographic film. The hotter the object, the whiter its



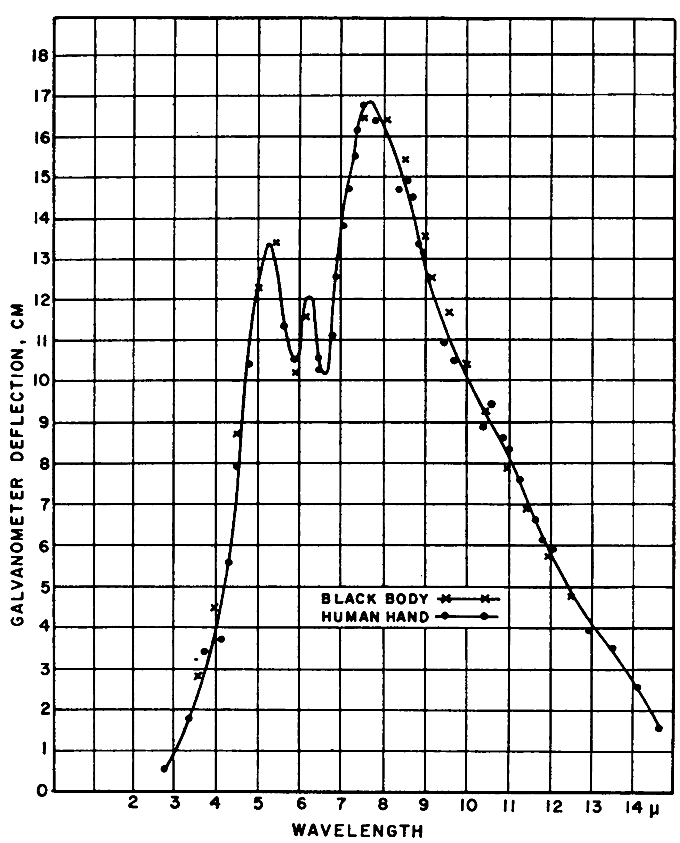


image. To facilitate calibration, eight density steps of known values are reproduced on each thermogram to constitute a quantitative thermal gray scale. The sensitivity of the camera may be varied, hence the full dynamic capability of the film may be utilized for any one of ten ranges of temperature differences. Thus, to change the film from white to black, a ΔT of 187°F is required at lowest sensitivity, while less than 1°F is needed at the highest setting.

Focusing from 1 foot to infinity is possible, and the field of view encompasses 10 angular degrees vertically and 20 angular degrees horizontally. If the full vertical scan is used, the total scan time is 13 minutes. This time is shortened proportionally if the scene being thermographed does not require the full 10-degree vertical scan. In a full 10- by 20-degree picture, 60,000 bits of temperature information are presented, and the optical resolution is 1 angular mil. With this resolution it is possible to record detail as small as ⅛ inch at a distance of 10 feet. The camera has two essential controls—one for sensitivity or contrast and one for brightness. By controlling sensitivity we can study the human body for large temperature differences or concentrate upon those that are rather small. Figure 4 shows four thermograms of the same hand and arm recorded at different sensitivities; the temperature differences recorded are quantitatively the same, but the contrasts are very different. Since the gray-scale steps are not linear with temperature, calibration curves are provided, as shown in Fig. 5. Thus the temperature differences may be read off immediately, and if any one gray-scale step is known from other measurements, actual temperatures may readily be deduced. The brightness adjustment enables the operator to set the middle of the gray scale to correspond with the average temperature of the object being studied.

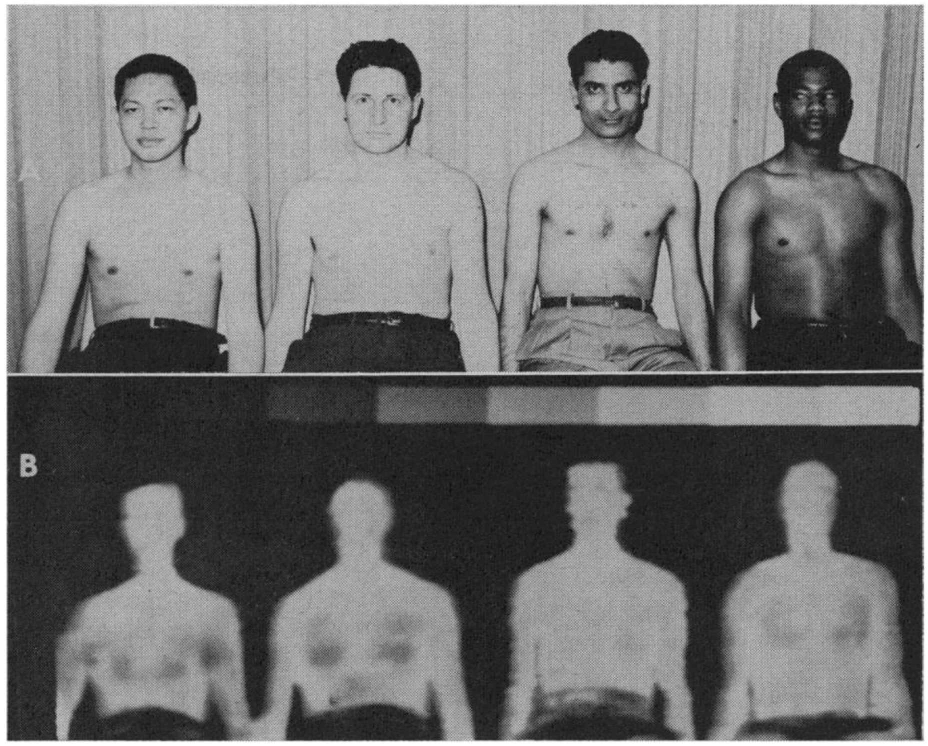
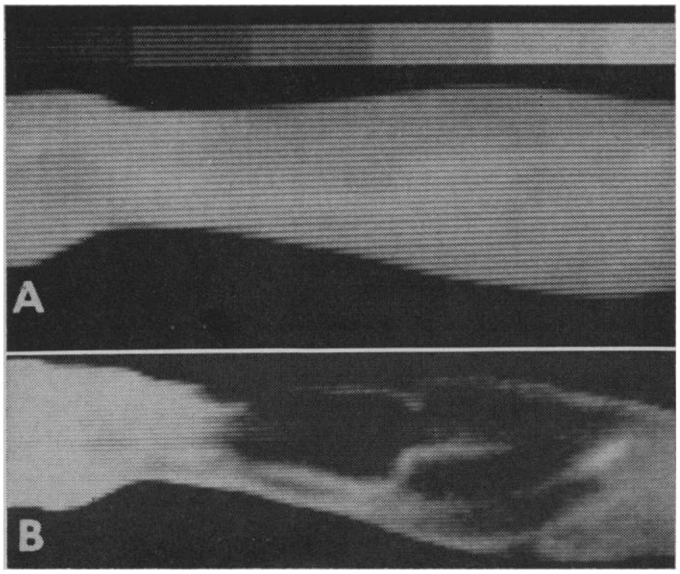


Fig. 7. Photographs and thermograms of members of four races. Pigmentation has no effect on the emission of long-wave infrared energy. Every individual emits infrared as a function of temperature alone. The visible differences result from different amounts of insulating fat.

Infrared Characteristics of Human Skin

In Table 1, the emissivity of human skin for infrared wavelengths greater than 4 microns is given as 0.99. In a very important series of papers by Hardy and others (*6*) this value was carefully studied and evaluated. In subjects of different types it was found to be sufficiently constant as to permit the conclusion that for all practical purposes all humans emit radiation in the long-wavelength infrared region as if they were "black bodies." Figure 6, taken from one of Hardy's papers (*7*), shows this very clearly for the infrared region from about 3 to 15 microns. Since ϵ is so close to 1, accurate broad-band measurements of the energy emitted by the skin (E) may be converted directly into values of T, and accordingly the surface of the human body is an ideal subject for thermography. The minute differences in the amounts of infrared radiation which are revealed by the halftones in the thermograms are directly proportional to temperature differences in different areas of the skin.

Human skin is relatively transparent to visible light and to infrared radiation of wavelength shorter than about 2 microns and therefore skin pigmentation produces great differences in the absorption and reflection power of skin for these parts of the spectrum. This pigmentation, however, plays no role in the longer-wavelength region, where the skin is an almost perfect absorber and, accordingly, a near-perfect emitter. This is illustrated in Fig. 7, which shows the reflection of visible light and the emission of infrared radiation for individuals of four races. It may be noted that highly pigmented areas such as lips, nipples, skin blemishes, and suntan do not show up in the thermograms, for they, too, have emissivities closely approaching 1 and are at the same temperature as the surrounding skin. In order, however, to avoid any spurious effects which might result from visible light or from transmissions or reflections of short-wavelength infrared, the spectral sensitivity of the camera is limited to those wavelengths for which human skin is essentially opaque or black. This is accomplished by the use of short-wavelength filters, such as the germanium lens to which the thermistor detector itself is attached, which is totally opaque from the visible region out to 1.8 microns and highly transparent from this point to about 15 microns. Thermograms of the human body made in this part of the spectrum are, therefore, true quantitative thermal maps of the skin. The average temperature of the healthy human body is about 98.6°F (37°C or 300°K), as measured orally. Even when the body is exposed to rather wide changes in ambient temperature this figure is closely controlled and is determined essentially by the basal metabolism of the body. The temperature of the skin, however, varies widely as a result of ambient temperatures and environ-



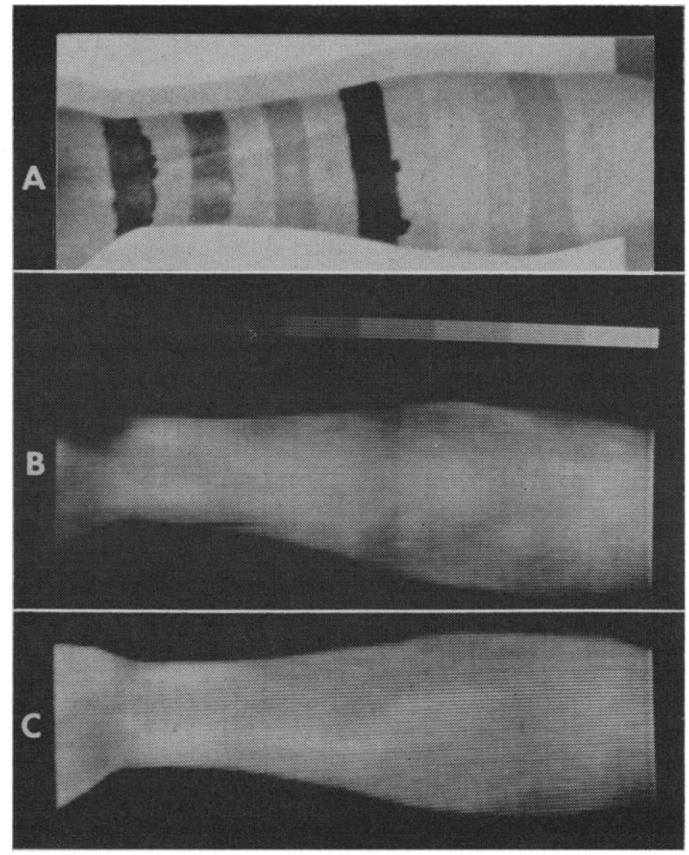


Fig. 8 (above). Thermograms showing that heat from sources within the body contribute more to contrast when the skin is cool than when it is warm. (*A*) Recording made at ambient temperature; (*B*) recording made after the skin had been cooled. Fig. 9 (right). (*A*) Photograph of an arm coated with stripes of (left to right) black lacquer, red nail polish, red lipstick, India ink, face powder, and eye shadow. (*B*) Thermogram of the coated arm made after the arm had been allowed to return to uniform temperature. The only effects are slight apparent coolings, due to lower emissivities of the materials used. (*C*) Thermogram of the arm before coating.

mental conditions and is determined by many factors. Under normal conditions it is lower than body temperature and varies roughly in the range from 85° to 95°F, but these limits are by no means rigid. Because of difficulties of instrumentation (*8*) there are very few accurate methods of determining skin temperature, and it is here that noncontact infrared radiometry and thermography can make valuable contributions.

Since the skin is the envelope which separates the internal structures of the body from the surrounding environment, its temperature must change grossly as a result of changes which take place either internally or externally. Its actual temperature at any one time is influenced by many processes.

Among these are the vascular activity within the skin itself, thermal conduction from both localized and diffuse heat sources within the body, insulation of clothing or grease, heat losses caused by the evaporation of perspiration or by convection air currents, and the radiant-energy exchange which is constantly taking place between the skin and the surrounding environment. We can say, for purposes of this discussion, that the actual observed skin temperature is the result of all of these contributions. Schematically this can be written $T_{observed} = \Delta T_{skin} + \Delta T_{body} + \Delta T_{insulation} - \Delta T_{evaporation} \pm \Delta T_{convection} + \Delta T_{radiation}$. A single measurement of skin temperature, therefore, can be of little medical value unless most of these variables are either eliminated or controlled.

Since the only two factors of major interest are ΔT_{skin} and ΔT_{body}, we must at least reduce the others to constants. Fortunately, this may readily be accomplished by removing the clothing from the part of the body to be studied; allowing the subject to remain at rest for 10 to 15 minutes in a cool room of constant temperature, free of air currents; and avoiding having any object appreciably hotter or colder than the room air in the subject's direct line of sight. Since the primary heat source for the skin is the heat conducted to it from within, the temperature of necrotic or dead tissue should approach room temperature very closely. Furthermore, we should expect to see no contrast in the thermogram if the temperature of the room is in equilibrium with the body's temperature of 98.6°F. Thermography should, therefore, always be carried out in a room where the temperature is thermostatically controlled and kept at about 70°F. Williams (*9*) and his co-workers recommended a room temperature of 66°F for best results. It is advisable to have the subject prone or reclining so that he will be comfortable and able to remain in one position during the scan time of the camera. In order to thermograph him in this position a front-surface mirror is mounted at a 45-degree angle just above the table upon which he reclines. This of course causes the thermogram to be reversed, right and left.

In cool air of constant temperature $\Delta T_{radiation}$ becomes important and must be understood and considered in interpreting the results. In a room at 70°F the temperature of the palm of your hand might, for example, be 90°F. This temperature is lower than the 98.6°F of the body because of heat losses; the most important of these arises from the fact that, under the conditions described, the palm is emitting more energy to the room than it is absorbing. If, now, you bring your two palms within half an inch of each other, these radiation losses are eliminated and you feel an immediate rise in temperature. If you hold your palms sufficiently close to each other for a fairly long time, their temperature will ultimately approach 98.6°F. This cross-radiation effect may be seen in all

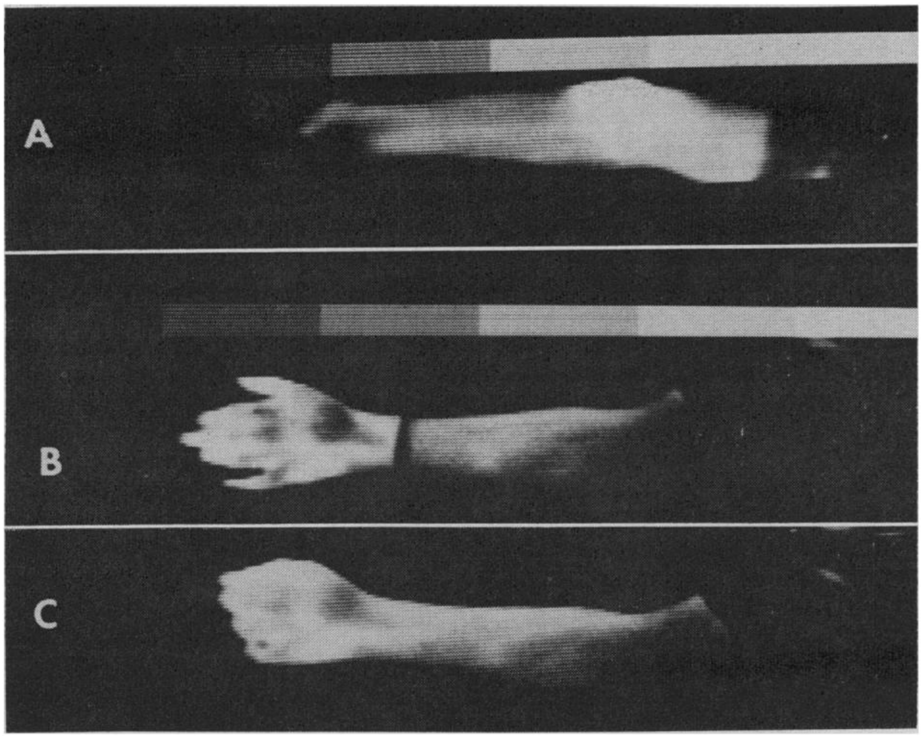


Fig. 10. Thermograms showing abnormal and normal blood flow. (*A*) Inflammation due to a bruised elbow; (*B*) restricted circulation due to a tight bracelet; (*C*) normal blood flow after removal of the bracelet.

body cavities or creases where skin opposes skin—for example, the navel, the inner canthus of the eye, the interior of the ear, the lip line, and the area between the fingers if they are held close together. During the 10- to 15-minute waiting period prior to thermography, subjects should attempt to minimize this effect, and if they are reclining, they should keep their arms extended. If this procedure is followed strictly, not only are the last four variables in the equation given above held constant but ΔT_{skin} itself may be reduced considerably by the lower temperature. In this case ΔT_{body}, the ΔT of primary medical interest, becomes the main contributor to contrast. Figure 8 shows two thermograms of the same arm, one recorded at relatively high ambient temperature and the other recorded after ΔT_{skin} had been reduced by local superficial cooling. The appearance of veins clearly shows the ΔT_{body} contribution.

Medical Significance

If thermograms are to be used diagnostically, they must be faithful recordings of skin temperature. Contrasts which appear must be primarily attributable to temperature differences within the body and must not reflect to any great extent the presence of foreign substances upon the skin. Fortunately, normal human skin is such a perfect emitter in the long-wave-length infrared that it is not possible to make it appear hotter (whiter), through applying foreign substances. Carbon black, India ink, lipstick, nail polish, rouge, and the like all have emissivities lower than that of skin and, accordingly, application of these substances can only have the effect of making the skin appear slightly colder than it actually is. When they are applied in small quantities, even this effect is small, as may be seen in Fig. 9. Obviously, if they are applied in large amounts, such materials may, by virtue of their insulating qualities, cause an area to appear much darker (colder) than it is. That they cannot create spurious hot spots is of significance.

Hardy (*7*) has shown that fat is a poor thermal conductor and a good insulator, as compared with moist muscle or skin, and thus we should expect the skin to appear cold above fatty concentrations, as it does in the thermogram. The skin over bony structures such as knuckles and kneecaps also appears cold, because of the absence of highly vascular tissues just beneath the surface. Hair, since it is avascular, comes to equilibrium with

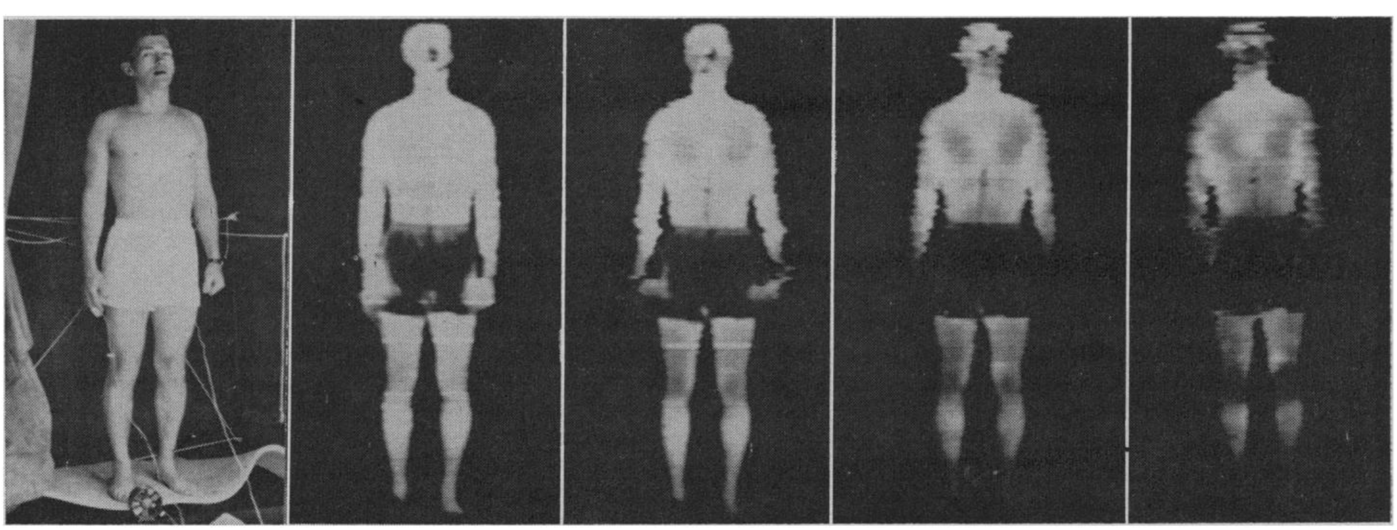


Fig. 11. Thermograms, recorded at 14-minute intervals, of a subject at ambient temperature of 32°F. Note the shivering and progressive cooling. [From Veghte and Solli (*10*)]

room temperature and consequently appears cold. On the contrary, skin directly above blood concentrations such as veins, hematomas, bruises, and infections appears hotter than normal. Figure 10*A* shows the elevated temperature of a bruised elbow. Figure 10*B* shows the other arm of the same patient. Although this arm was normal, the impairment of circulation caused by the tight bracelet is clearly visible. Figure 10*C* was recorded shortly after removal of the bracelet. Heavy scar tissue and uninfected cystic lesions such as ganglia, because of their low vascularity and low metabolism, appear colder than surrounding areas. On the other hand, recent fractures appear hotter than adjoining areas.

Thus, as might have been expected, we find that high vascularity or high metabolism elevate the skin temperature, while cysts, benign inactive processes, concentrations of fat, or other conditions of low vascularity result in areas of lowered skin temperature.

Veghte and Solli (*10*) published a significant paper on results with an infrared camera of the type described. Air Force personnel were thermographed during exposures of up to 56 minutes to outside temperatures of 32°F. A series of thermograms taken at 14-minute intervals (Fig. 11) reveals the relative rates at which different skin areas cool during such exposure. These studies are being continued by the Air Force Arctic Medical Laboratory at Fairbanks, Alaska, in connection with research on protective clothing.

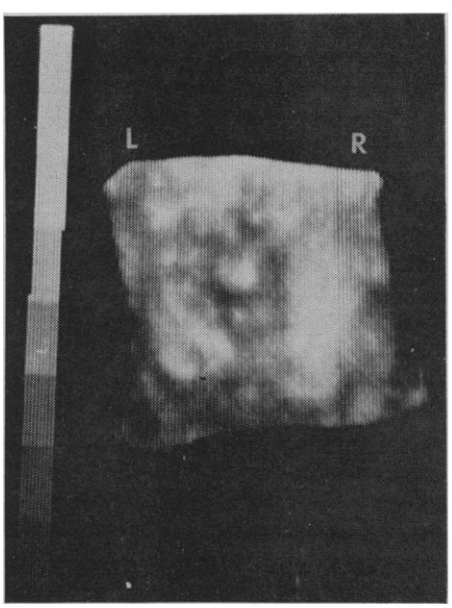


Fig. 12. Thermogram that supports a diagnosis of appendicitis. Inflammation in the lower right portion of the abdomen is indicated by the increase in temperature of the skin in that region. The thermogram is reversed left to right because of mirror reflection.

Table 2. Results of infrared measurement of skin temperature in 100 cases of lump in one breast. [After Williams *et al.* (*9*)]

Disorder	No. of cases	Temperature	
		Rise	No rise
Abscess	4	4	0
Carcinoma	57	54	3*
Fibroadenoma	10	6	4
Cyst	18	1*	17
Adenosis	6	0	6
Fat necrosis	2	0	2
Duct stasis	3	0	3

* Exceptional case.

The extent to which thermograms may be likened, for purposes of identification, to gross fingerprints of individuals will have to await the compilation of sufficient data. There is, however, a good indication that this is a valid comparison. We can say definitely that when repeat thermograms are made on the same individual, duplicate thermal patterns are obtained, unless, of course, there has been some change within the body.

Diagnostic Applications

Thermograms made under controlled conditions such that ΔT_{body} becomes the primary contributor to thermal contrast should yield information of considerable diagnostic value.

Lawson (*11*) observed in two cases of metastatic breast cancer that the skin overlying the affected areas was definitely hotter than that of surrounding areas. In a later paper (*12*) he reported on several thermograms made with the forerunner of the camera described. In one case of cancer the overlying skin appeared to be hot, while in the case of a cyst, the skin temperature appeared to have been lowered. In a third paper (*13*) Lawson reported the successful application of thermography to the assessment of skin burns and frostbite. More recently (*14*) he has reported on measured temperature differences between benign and malignant lesions.

Williams *et al.* (*15*) have reported on an extensive series of infrared studies; in their second article (*9*) they include data on 100 patients, each with a lump in one breast. Both breasts were scanned, from a distance of 1 centimeter, with a hand-held thermopile sensitive from the visible range to about 9.5 microns; significance was attributed to measured temperature differences of 1°C or more in contralateral symmetrical areas of the skin. The interesting results of these workers are shown in Table 2.

In April 1962, prompted by our work and the work of Lawson and of Williams *et al.*, the Albert Einstein Medical Center, Northern Division, in Philadelphia, initiated a cooperative survey program under the medical supervision of J. Gershon-Cohen, director of the department of radiology. This program was designed to develop thermographic techniques and to explore the overall potential of thermography as a diagnostic tool. The program is continuing, and the results will be reported at a later date.

Several interesting thermograms are presented here to illustrate the apparent potential of this method as a diagnostic tool.

Case 1: Appendicitis. The subject, a 12-year-old male, had abdominal pains throughout the morning and was thermographed at noon (Fig. 12), just after the family physician had suggested that the pains might be caused by an inflamed appendix. Immediately after thermography the patient was hospitalized; he was found to have no fever and no increase in the number of white blood cells. Throughout the afternoon the pain became more localized over the appendix. Around

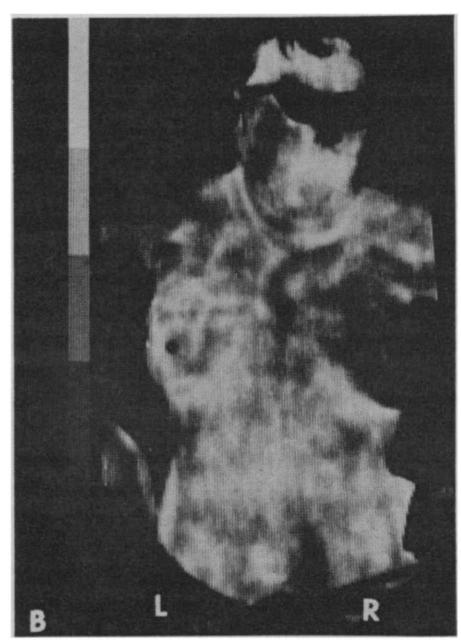


Fig. 13. Carcinoma of the breast. The thermogram reveals an average of 3°F higher skin temperature over the entire left breast than over the right.

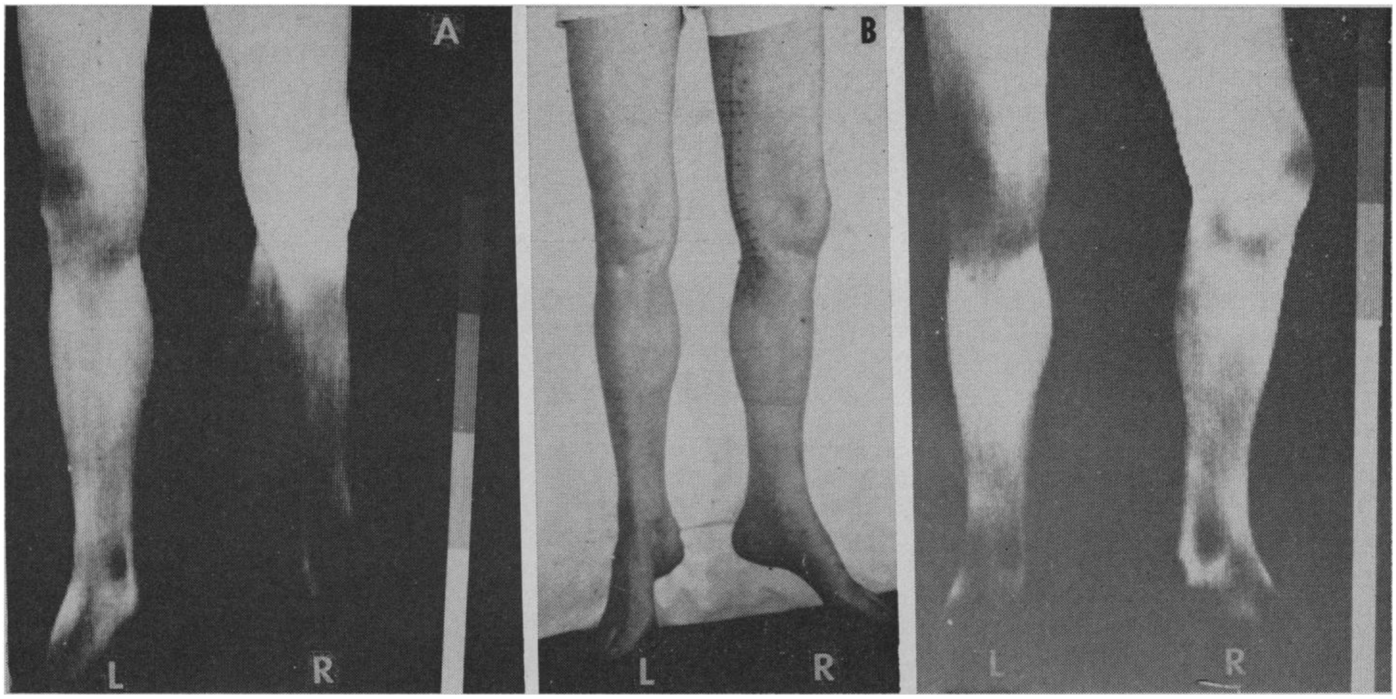


Fig. 14. Thermograms and photograph of a patient with arterial occlusion. In a preoperative thermogram (*A*), temperature differences up to 7°F were noted below the knee. A mid-thigh amputation was considered. Instead, a sympathectomy was performed and a bypass was inserted (see *B*). Restoration of blood flow is shown in *C*.

6:30 P.M. the patient developed a slight fever, accompanied by a definite increase in the number of white cells. These symptoms led to a clinical diagnosis of appendicitis, and at about 7:30 P.M. the appendix, acutely inflamed, was removed.

Case 2: Carcinoma of the breast with metastases. The patient, a 56-year-old female, reported a firm swelling in the left breast of 3 weeks' duration. Clinical examination revealed a large mass in the upper outer quadrant of the left breast. X-ray films were compared with films made 2 years previously. (At that time the patient had complained of pain in the left breast. The roentgen diagnosis at the time was bilateral fibroadenosis, more marked in the upper outer quadrant of each breast.) Roentgen re-examination revealed the previously described bilateral fibroadenosis. In addition, however, a dominant, irregular infiltrate was now apparent in the upper outer quadrant of the left breast. This was believed to represent an extensive malignancy. Thermography (Fig. 13) confirmed these conclusions by showing the entire left breast to have an average skin temperature about 3°F higher than that of the right breast. A left radical mastectomy was performed, after study of a frozen section led to a diagnosis of extensive duct cell carcinoma with axillary lymph node metastases.

Case 3: Arterial occlusion. A 68-year-old male experienced pain and the feeling of cold for a period of 5 or 6 weeks. Examination revealed generalized arteriosclerosis and an aneurysm of the aorta. Because the studies, including thermography, revealed advanced occlusive vascular disease of the right superficial femoral artery, a sympathectomy was performed and a saphenous bypass posterior tibial graft was inserted. This resulted in restoration of the pedal pulsations and relief of the patient's symptoms. Figure 14*A* is a preoperative thermogram of this patient. Note the equivalent skin temperatures of the thighs, the elevated temperature of the right knee (about 4°F higher than that of the left), and the sharp decrease in temperature (about 6°F) just below the right knee. Figure 14*C*, made 30 days after Fig. 14*A*, shows dramatically the successful restoration of blood flow.

Summary

Human skin is an almost perfect emitter of infrared radiation in the spectral region beyond 3 microns. This energy may be recorded as a thermogram to yield a quantitative temperature map of the skin. If the nude subject has remained quiet in a cool room for 10 to 15 minutes prior to thermography, the skin temperatures are determined largely by the vascularity of the skin itself and by the heat conducted from within the body. Since, under these conditions, the contrasts which appear arise essentially from the internal sources of heat, the resulting thermograms yield information concerning certain pathological conditions within the body (*16*).

References and Notes

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