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74

EFFECTS OF HIGH INTENSITY RADIANT ENERGY ON SKIN

I. TYPE OF INJURY AND ITS RELATION TO ENERGY DELIVERY RATE

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G. E. Sheline - E. L. Alpen
P. R. Kuhl - A. Ahokas

USNRDL-346

U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY
SAN FRANCISCO 24, CALIFORNIA

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G. E. Sheline
E. L. Alpen
P. R. Kuhl
A. Ahokas

USNRDL-346
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DATE ISSUED: 29 May 1952

ABSTRACT

USNRDL-346

Burn lesions were produced by radiant energy, 3100°A to 22000°A, on depilated rat skin. The gross and microscopic pathological changes so caused are described and correlated with the amounts of incident energy and the rate of energy delivery. Within the limits studied, 0.2 to 64 cal./cm.^{2}/sec. and 0.1 to 8.0 seconds, it was found that increasing the rate of energy delivery lowered the amount of energy required to produce a specified degree of tissue injury. The tissue changes were in many respects similar to those described for contact burns of the skin of rats and other animals. The findings suggest the action of such intensities of this spectrum of radiant energy is essentially of a thermal nature.

In recent years the preponderance of experimental work on thermal injury has dealt with the systemic effects which result from burns. Fluid and electrolyte changes, anemia, malnutrition and renal failure have been widely studied. It seems probable that an understanding of the local damage, both immediate and delayed, would be useful in anticipating the nature of systemic changes and determining proper local management. Significant steps in this direction have followed the studies of such groups as Henriques and Moritz at Harvard, Pearse, Payne and Hogg at Rochester, and Leach, Peters and Rossiter at Oxford. The present study deals with the local action of high intensity radiant thermal energy on the skin of the rat, and the manner in which the effects differ when the time of exposure to the thermal source and the radiant intensity are varied.

In a study of experimental burns of dog skin produced by flame, hot objects, radiation from cautery tips, and burning liquids, Elman and Lischer (1) classified the burns produced in dogs into three types. In order of increasing severity they were: (a) an inflammatory reaction with edema but no necrosis, produced by flame, radiation, or hot liquids; (b) wet necrosis manifest in 1-2 days as a swollen, moist, necrotic area, produced by immersion in hot water (100°C) for 2-15 seconds; and (c) dry necrosis with immediate hardening and coagulation of the tissue, produced by immersion in hot water (100°C) for 20 seconds, or longer. The dry necrotic lesion tended to slough easily, was without edema and was often characterized at the margins by a wet type of necrosis. Leach, Peters, and Rossiter (2) described the gross and microscopic changes of guinea pig skin produced by a hot iron. The gross changes for a one minute contact were; transient erythema (50°C), edema (55 and 60°C), scab formation (55°C), immediate blanching with change to erythema within 5 minutes (55 and 60°C), incipient blister with lifting of prickle cell layer and a tendency for the epidermis to rub off easily (60 and 65°C), and heat fixation with coagulation of tissue proteins (70 and 80°C). The microscopic changes were, in general, those usually found in necrosis. With milder burns there was cellular disintegration; with the more severe burns heat coagulation and changes in structure and staining affinities of the collagen fibers occurred. In the more severe burns there was a peripheral shell of changes characteristic of the lower temperature burns.

An excellent description of the gross and microscopic changes produced in pig skin by hot water and hot air (to 900°C) has been presented by Moritz (3). The earliest visible evidence of epidermal injury was chromatin redistribution and swelling of the nuclei. Further injury was evidened by cytoplasmic swelling and disintegration plus nuclear pyknosis and impairment of the epidermal-dermal attachment. Transepidermal coagulation next appeared. Desiccation and carbonization occurred with further increases in the temperature of the burning agent. The first dermal change seen was vascular constriction followed by dilation. However, when the rise in temperature was sufficiently rapid and high, the vessels were fixed in the constricted state. Coagulation occurred when the dermis was heated to 55°C for a sufficient period. Moritz reported that low intensity burns showed a non-coagulative necrosis in which the involved tissue could undergo autolysis and organization. In contrast, high intensities resulted in coagulative necrosis with the dead tissue disposed of by sequestration without autolysis or organization.

Pearse, Payne and Hogg (4) described the pathological changes occurring in pig skin following exposure to a magnesium flash for 0.34 second. In their pigs a mild burn was characterized by erythema, whereas a moderately severe lesion had a central gray-white area of dry cutaneous necrosis. Some time after burning this necrotic center became edematous, indurated and covered by a brown crust. Histologically the epithelium of the moderately severe lesion exhibited an abrupt change from burned to normal and the depth of penetration of the dermis was reflected by coagulation of the collagen fibrils. In the more severe burns demarcation was not as marked laterally or in depth as in the mild or moderately severe burns. These authors stated that a characteristic of the flash burn was the method of healing in that the burned tissue represented "a coagulative 'fixed' type of necrosis, with eschar formation and subsequent sequestration, rather than the organization in the non-coagulated necrotic tissue of the moderate temperature burn." They concluded that the healing process in flash burns is different from that in moderate temperature burns. However, Evans (5) studied the clinical course of two patients with large area flash burns and found them in every way similar to those of patients suffering from other types of burns.

Buettner (6, 7) has carried out an excellent mathematical analysis of the temperature gradients in skin established by contact heat, non-penetrating radiant energy and penetrating radiant energy. However, because of the nonhomogeneity of the skin and the uncertainty associated with certain of the values for the absorption, scattering and heat conductivity coefficients, the theoretical conclusions are of limited usefulness.

Equipment

A 36 inch standard Navy searchlight fitted with a modified Mole-Richardson arc mechanism was used as the thermal source. The arc was operated at 76 volts and 170 amperes DC with 16 mm. National Carbon Co. "Super High Intensity Searchlight Carbons." The arc crater was at the focal point (focus a, Fig. 1) of a paraboloidal reflector which collimated the light. The main portion of the beam passed through a partially reflecting plane glass* surface and was refocused by a second paraboloidal reflector. The reflected portion of the beam was focused by a third paraboloidal reflector. The main beam was used as the thermal source for the burns, while the reflected portion permitted a continuous monitoring of the beam intensity. For calibration a black body calorimeter was placed at each of the two foci of the divided collimated beam: the first calorimeter, at focus b, measured the energy in the main beam; the second or monitoring calorimeter, at focus c, measured the portion reflected from the beam splitting mirror. In this way a ratio between the two portions of the beam and a direct measurement of the energy delivered to the burn area were obtained. Using data obtained by the monitoring calorimeter and employing this previously determined ratio permitted a calculation of the energy delivered by the main beam when an animal holder was substituted for the first calorimeter. Under these operating conditions the maximum intensity which could be delivered to the receiver was 85 calories per square centimeter per second. Throughout this paper references to "energy applied" mean the calorimetrically measured energy values and no correction is made for reflection or scattering caused by the animal's skin.

The spectral distribution of the energy incident on the receiver was essentially the same as that from a 5000° to 6000°K black body radiator with the exception of the attenuation produced by the glass searchlight window and beam splitter. There was essentially no energy below 3100°A nor above 22000°A in the final condensed beam.

The searchlight was mounted on a pivot and was rotated about its axis by an electric motor. Use of a gear box and changing the motor speed permitted a wide range of constant rotational speeds for the searchlight. In this manner the time during which the energy was delivered to the receiver was varied. The time - energy curve for such an energy pulse was bell shaped or nearly triangular. The time of exposure was defined as the time required to deliver the total energy assuming it was all delivered at the maximum rate found for the energy pulse.

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* Libbey-Owens-Ford "Color Clear" glass.

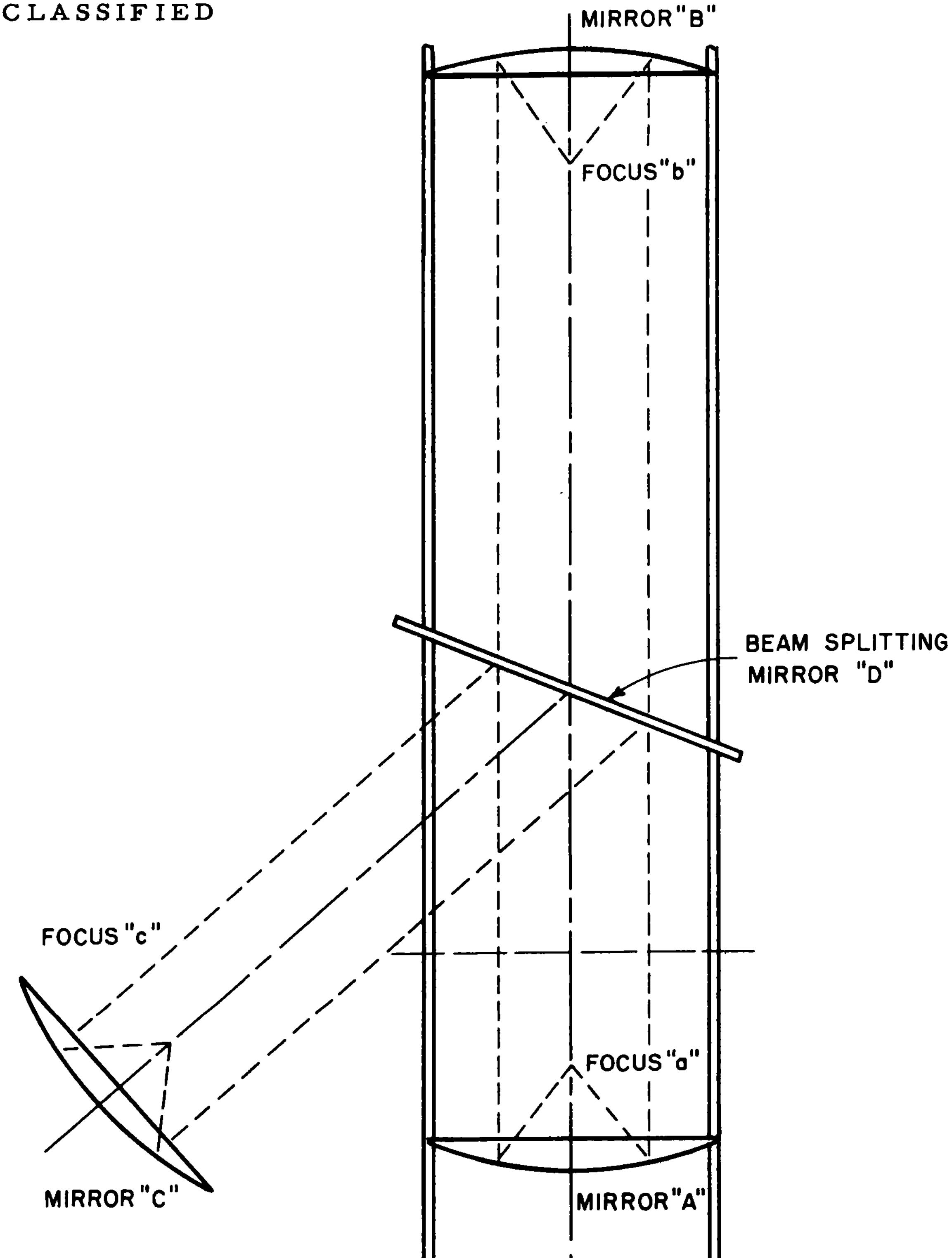


FIG. 1. DIAGRAM OF EQUIPMENT USED FOR THERMAL RADIATION BURNS. A, B, and C are paraboloidal mirrors. A and B have front aluminized surfaces. The carbon arc crater is at focal point a, the object to be burned at focal point b, and the monitoring calorimeter at focal point c. The glass sheet, D, reflects a portion of the entire collimated beam to mirror C.

Change of intensity was accomplished by placing different combinations of wire screen, expanded metal, or drilled metal sheets in the collimated beam between the searchlight window and the beam splitting mirror (Fig. 1). Thus the beam intensity could be varied in discrete steps from a fraction of one per cent of full beam intensity to full beam intensity.

The animal holder shielded the animal from all radiation originating from the carbon arc except that passing through a 0.9 cm. diameter aperture placed at the focus of the main beam. The aperture was defined by a hollow copper plate through which water was pumped from a thermostated (35°C) water bath. The front surface of this plate was machined in a series of steps so dimensioned that light originating from the arc and reflecting off a step would not enter the aperture. The inner step, which actually defined the aperture, was only 1/64 inch thick and was covered on the inside by a plastic film. The rest of the inside of the holder was asbestos lined to prevent contact between the animal's skin and the metal holder.

Methods

Female Sprague-Dawley rats from the laboratory breeding colony were used. The animals were sexed at birth, segregated and maintained on a standard diet of Purina Laboratory Chow.

At 50 to 60 days after birth the animals were depilated. After close clipping under light nembutal anesthesia, a thick paste of a commercial strontium sulfide depilatory was applied to the right and left flank and hip areas and allowed to remain approximately 4 to 5 minutes. The paste was washed off in a stream of cool water, a rinse of 0.1 per cent acetic acid was applied and a final rinse in cool water given. The depilation was followed by an immediate application of anhydrous lanolin. Lanolin was reapplied 2 and 4 days following depilation. The animals were burned on the seventh or eighth day after depilation. In a study made on the effect of this depilation technique on rat skin it was found that at 7 to 8 days after depilation the skin was essentially normal and regrowth of hair shafts had just reached the epidermal surface (8).

For exposure, the animals were anesthetized by subcutaneously administered sodium nembutal solution (40 mg./kg.) and held lightly in position against the aperture of the animal exposure holder. A burn was administered to the skin over the left and the right hip.

Immediately after burning, the physical appearance and size of the lesion were recorded and a 35 mm. Kodachrome photograph made. Twenty-four hours later the changes in physical appearance were recorded and the lesions again photographed. No long term observations were made on these animals.

For histological study the burn from the left hip was excised, mounted on a wooden tongue blade with Michel wound clips and fixed in Bouin's solution. The specimens were imbedded, sectioned and stained with haemotoxylin and eosin. Unless otherwise noted all biopsies were done at 24 hours after the burn exposure.

A series of control sections taken from the equivalent skin area of non-burned animals was used as a basis of comparison for the changes induced by thermal radiation. These sections were taken after depilation in the same manner, and at the same interval after depilation, as the burned group. All histological conclusions are based on data taken by two observers, each of whom examined each slide at least three times on different days.

RESULTS

USNRDL-346

The initial burns produced in this study demonstrated that a sufficient increase in the energy dose incident on the animal's skin produced a burn of different gross appearance. This was true over a wide dose range, varying from that necessary to produce a barely perceptible tissue change to that for complete destruction of the entire skin thickness. Furthermore, when a particular dose was given to several animals the burns produced appeared very much alike. The gross appearance of the lesion in animals burned on different days was consistent. Similar results were apparent with respect to the histological appearances of these burns.

On the assumption that lesions resulting from greater amounts of energy represent more severe burns, severity spectra were set up according to both their gross and histological appearances. It seemed that such spectra could serve as common bases against which other burns could be compared. Of the series of burns made with varying energy doses, 2 to 67 cal./cm.^{2}, and with varying times of delivery, 0.1 to 8 seconds (Table 1), the series of burns produced by the 0.4 second exposures was arbitrarily selected as the common standard against which the other burns would be compared.

TABLE 1

EXPOSURE TIME AND THERMAL DOSE RANGE

Exposure Time (sec.)	Range of Doses Administered (cal./cm.^{2})	Number of Animals (2 burns/animal)
0.1	3.0 - 6.4	14
0.2	2.1 - 11.2	20
0.4	2.2 - 24	27
0.5	3.0 - 28	10
0.8	2.5 - 42	32
1.0	1.6 - 43	9 (4 burns/ animal)
2.0	13 - 67	38
4.0	2.2 - 54	38
8.0	1.7 - 40	32

Gross Observations

Since the 0.4 second exposure series was used as the reference against which burns of other exposure times were compared, the pathologic changes found for this series will be given in detail (for a brief summary see Table 2). Immediately after burning, the minimum change detectable was an erythema which developed within 2 to 5 minutes and faded within the first one-half hour; 3.5 to 4.0 cal./cm.^{2} were required to produce this lesion. A more lasting erythema was not seen in these studies. When the incident energy was increased to 4.5 cal./cm.^{2}, a white lesion, which exhibited a slight pinkish tinge, was found. As the amount of energy was increased over that necessary to produce this minimal white lesion, the pinkish cast disappeared and the burned area became a more pronounced white. In the region of 7 to 8 cal./cm.^{2} there was a light gray cast to a predominately white lesion. This gray became more pronounced when the energy delivered was increased and reached a maximum at about 12 to 15 cal./cm.^{2}. In the latter energy range multiple tiny, thin walled, empty vessicles appeared on the surface of the gray lesion. These were frequently scaly in appearance, and were found at energies up to 20 to 25 cal./cm.^{2} At energy deliveries greater than 25 cal./cm.^{2} frank charring of the skin occurred.

Twenty-four hours after burning the animals exposed to 3.5 to 4.0 cal./cm.^{2}, i.e., those exhibiting the early transient erythema, had a white lesion comparable with the minimal white of the 4.5 cal./cm.^{2} zero time observation.

TABLE 2

SUMMARY OF OBSERVED GROSS AND MICROSCOPIC APPEARANCE FOR 0.4 SECOND BURNS

Energy (cal./cm.^{2})	Epidermal Changes		Dermal Changes			Panniculus Carnosus Changes	Gross Surface Description	
	Nuclei	Cytoplasm	Vasc. Supp.	Collagen	PMN		Immediate	24 Hrs.
3.0	No change seen 0*		Inc. at surface	No change (1)*	None	No change (0)*	Normal	Normal
3.5- 4.0	Pale Eosinophilic (1)	Pale, swollen	Inc. upper third	No change (1)	Frequent	No change (0)	Transient erythema	White
4.8	Epidermis absent (1a)		Necrotic Plug Over Surface Mod. inc.	Minim. coag under plug	Massive (2)	Slight nuclear pyknosis (1)	White	Serous br. crust
5.3	Pyknotic, basophil. (2)	Thin, no structure	No incr.	Mod. Coag., some struct. lost (3)	Few	Increasing nuc. pyknosis (1)	White	White with spotty ser. scabs.
5.9- 6.1	Same as 5.3 (2)		No vess. upper 1/3	Same as 5.3 (3)	None	Increasing nuc. pyknosis (1)	White	White with few brown spots
7.0- 7.2	Same as 5.3 (2)		No vess.	Same as 5.3, some basophilia (4)	None	Vasc. dil. with nuc. pyknosis (2)	Light gray	Light gray
8.2	Same as 5.3 (2)		None	Compl. coag., upper 1/3 homogen. (4)	None	All vessels damaged. Incr. pyknosis (2)	Darker gray	Light gray
9.1	Same as 5.3 (2)		None	Thinned, 2/3 homogen. (4)	None	Same as 8.2, marked nuc. pyknosis (2)	Dark gray	Gray

* Figures in parentheses are severity scores assigned as described in the text.

TABLE 2 (Continued)

SUMMARY OF OBSERVED GROSS AND MICROSCOPIC APPEARANCE FOR 0.4 SECOND BURNS

Energy (cal./cm.^{2})	Epidermal Changes		Dermal Changes			Panniculus Carnosus Changes	Gross Surface Description	
	Nuclei	Cytoplasm	Vasc. Supp.	Collagen	PMN		Immediate	24 Hrs.
12.5	Multiple exploded blisters (3)		None	Inc. basophil., bottom 1/3 foamy (5)	None	Same as 9.1	Dark gray	Gray
15.4	Same as 12.5 (3)		None	Inc. basoph. (5)	None	Same as 9.1 (2)	Dark gray, scaly	Dark gray, scaly
20.5-21	Thin, structureless fragments (3)		None	Marked thinning (5)	None	Coagulated, basophilic (3)	Dark gray, scaly	Dark gray, scaly
22 -23.9	Epidermis absent (4)		None	Marked baso., low 1/2 bubbly (5)	None	Same as 20.5 (3)	Dark gray, scaly	Dark gray, scaly

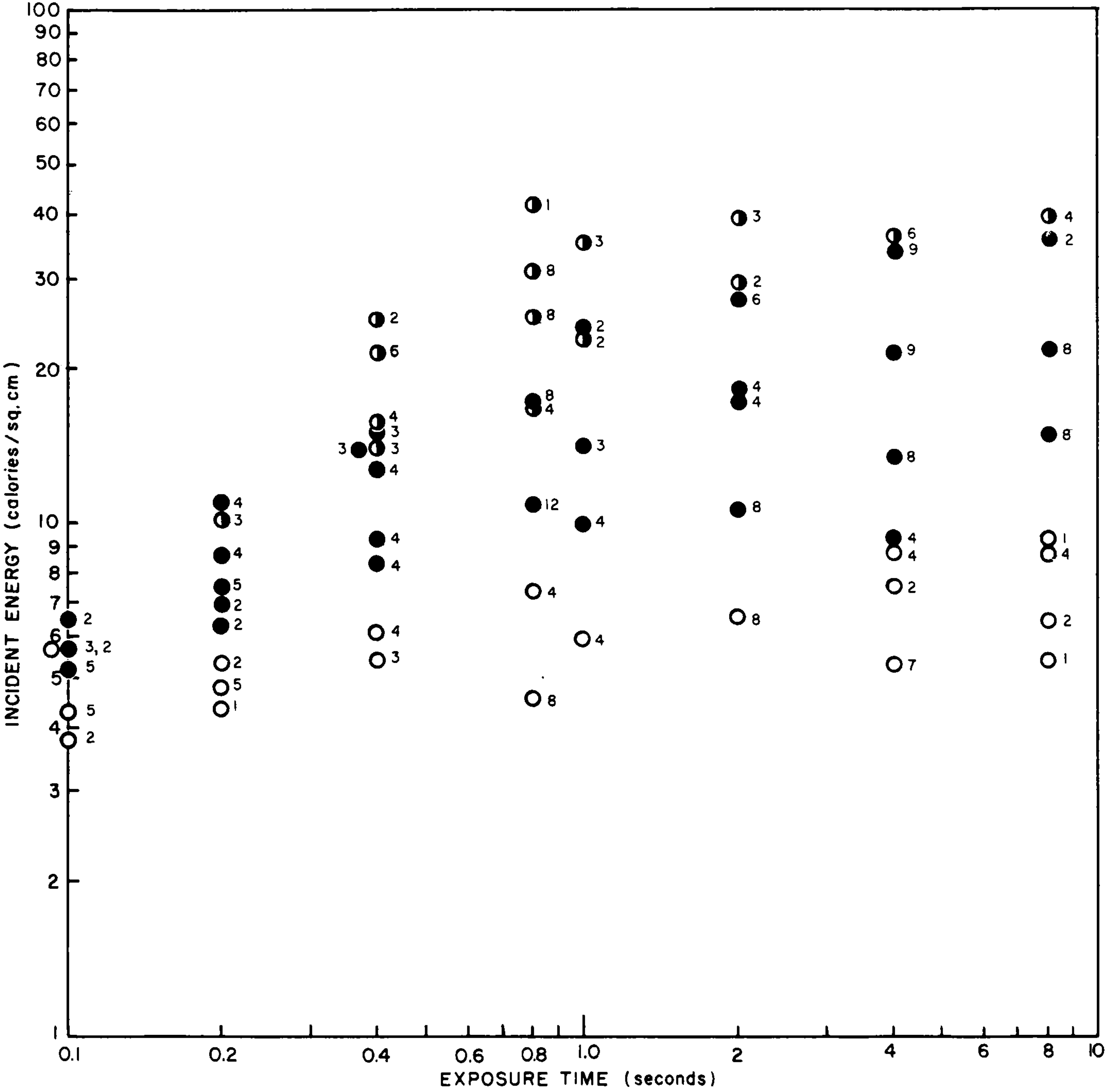
The animals having white burns (4.8 to 6.1 cal./cm.^{2}) at zero time had, at 24 hours, areas of serous encrustation overlying the white lesion. This serous encrustation usually replaced completely, or nearly completely, the white coagulum at the lower energy range (4.5 cal./cm.^{2}) and diminished in area at the higher energies. In the range 5.5 to 6.0 cal./cm.^{2} the serous encrustation was infrequent and had a peripheral distribution. The burns produced by 7 cal./cm.^{2} or above were essentially the same at 24 hours as immediately after burning.

Other burns produced in exposure times of 0.1 to 8.0 seconds showed spectra of changes similar to the spectrum seen at 0.4 second. Certain features of these spectra, as seen immediately after burning, are indicated in Fig. 2. A burn plotted as "white" or "gray" is predominately the color plotted; however, some of the lesions in the transition zones contained areas of both colors. In this figure, all variations in degree of grayness were classed together. The number of times a particular observation was made is shown next to the plotted symbol. The lowest energy at which an initially white lesion was found was 3.7 cal./cm.^{2} at 0.1 second, 5.3 at 0.4 second, 5.9 at 1.0 second, and 5.5 at 8 seconds. For these same exposure times the minimum incident energy in cal./cm.^{2} necessary to produce (a) a gray color was 5.0, 8.1, 9.9 and 15.5, and (b) a scaly surface was 13.5, 24, and 40, at 0.1, 0.4, 1, and 8 seconds respectively. Since the white color gave way to gray as the energy was increased, the minimum energy for grayness was also the maximum for white. The appearance of scale does not preclude the simultaneous presence of gray; in fact scale always occurred on the surface of a gray lesion. Data were also obtained for the energies at which transient erythema and charring appeared. These data did not present anything beyond that indicated in Fig. 1 and are not shown.

Histological Observations

In Table 2 the major histological changes, for 24 hour biopsies, of the 0.4 second burns are briefly summarized and correlated with the gross observations. The only change found in the 3.0 cal./cm.^{2} burns was an increase in the number of red blood cell-filled capillaries near the surface of the dermis. When the applied energy was increased to 3.5 to 4.0 cal./cm.^{2}, the epidermis stained very pale and its cells were swollen. The superficial dermis showed an increase in vascularity and a scattered infiltration of polymorphonuclear leucocytes (PMN). A slightly more severe burn, 4.8 cal./cm.^{2} (0.5 sec.), exhibited a complete loss of epidermis and a replacement of the upper third of the dermis by an eosinophilic, structureless mass beneath which there was an increased vascularity and a massive PMN infiltration. At 5.3 cal./cm.^{2} the epidermis was thin and adherent to the dermis, except for occasional small areas of separation in which a material staining like serum was present. Except for pyknotic nuclei the epidermis was without visible structure. The epidermis remained essentially without further change until the applied energy reached 12.5 cal./cm.^{2}. At 12.5 cal./cm.^{2} the appearance of the epidermis was that of many tiny, exploded, empty blisters. The blisters became more fragmented with higher energies and the entire epidermis was absent at 22 to 23.9 cal./cm.^{2}

FIG. 2. A PLOT OF TOTAL ENERGY DELIVERED - EXPOSURE TIME FOR THREE TYPES OF BURNS. ○ indicates the burn surface was white, while ● and ◑ indicate a gray and scale burn, respectively. The number next to each symbol shows the number of observations represented by the symbol.



At 5.3 cal./cm.^{2} the vascularity and PMN infiltration, noted in the dermis at 3.5 to 4.8 cal./cm.^{2}, had diminished. Patent dermal vessels (except in the extreme base of the dermis) and PMN were not seen at energies of 7.0 cal./cm.^{2} or higher. The dermal collagen showed a moderate degree of coagulation (or homogenization) with slight loss of its reticular structure at 5.3 cal./cm.^{2} With higher energy levels these changes became more pronounced and extended deeper into the dermis until at 12.5 cal./cm.^{2} the entire dermis was coagulated and there was no normally appearing reticular structure. At this energy the upper dermis had a splotchy, basophilic appearance, and the portion of the dermis immediately above the panniculus adiposus appeared frothy or bubbly. Above 20.5 cal./cm.^{2} the dermis was markedly thinned. The hair shafts protruded from the surface, suggesting that the dermis had shrunken away, and the bubbly character predominated in the deep half of the remaining dermis.

Slight nuclear pyknosis appeared in the panniculus carnosus at 5.3 cal./cm.^{2}; however, 7 to 8 cal./cm.^{2} were required to produce vascular damage. Nuclear pyknosis and vascular damage became progressively more pronounced as the energy was increased. Mild vascular changes were usually accompanied by PMN infiltration. Above 20.5cal./cm.^{2} the panniculus carnosus was basophilic and coagulated.

Based on the spectrum of histological changes found for the 0.4 second series and two energy groups from the 0.5 second series of 24 hour biopsies, arbitrary numerical grading systems were devised for the epidermis, the dermis and the panniculus carnosus (Table 2). The epidermal changes were assigned five grades ranging from 0 to 4; the dermis, seven grades from 0 to 6; and the panniculus carnosus, four grades from 0 to 3. Each of the three layers of a burn lesion to be evaluated was matched with the description from this comparison series, and the numerical grade of the description most applicable selected. The grades presented in Table 3 represent the average of the grades assigned to two, three or four lesions of nearly the same incident energy and delivery time by two graders. The lesions were grouped in series of approximately equal energies but of varying delivery times. In eight of the nine equal energy series, the severity score was lower for those burns delivered over the longest period of time. A comparison of the scores within each of the three tissue layers of the 9 equi-energy series showed that in every case a burn of longer delivery rate received a score either equal to or lower than the next more rapidly delivered burn in the series. In 18 of the 27 layers, the score was less for the longest exposure than for the shortest. The variation among the total scores within each series was less for the higher calorie burns.

TABLE 3

COMPARATIVE SEVERITY SCORES FOR NINE APPROXIMATELY EQUI-ENERGY BURN SERIES*

Series	Exposure Time (sec.)	Energy (cal. /cm.^{2})	Comparative Severity Scores			
			Epidermis	Dermis	Panniculus Carnosus	Total
A	0.1	3.0-3.6	1	2	0	3
	0.2	3.2-3.3	0	1	0	1
	0.5	3.0	0	1	0	1
	8.0	3.5-3.8	0	0	0	0
B	0.1	4.1-4.4	1	3	1	5
	0.2	4.3-4.6	1	2	1	4
	0.5	4.8	1	2	1	4
	0.8	4.5	1	2	1	4
C	0.1	5.5-5.6	2	4	1	7
	0.4	5.3	2	3	1	6
	4.0	5.2-5.4	1a*	2	1	4a
D	0.2	8.5-8.8	2	4	2	8
	0.4	8.2	2	4	2	8
	4.0	8.6-9.0	1a	2	1	4a
E	0.4	9.1	2	4	2	8
	8.0	9.1-9.6	2	3	1	6
F	0.8	10.6-10.7	2	4	2	8
	2.0	10.8-11.3	2	4	2	8
G	0.8	16.3-16.5	3	5	3	11
	8.0	16.5-17.1	2	4	2	8
H	0.4	20.5-23.9	3	5	3	11
	0.8	25.0	3	5	3	11
	4.0	20.6-22.5	2	5	3	10
	8.0	22.1-22.8	2	5	3	10
I	0.8	41.0	4	6	3	13
	2.0	38.3-40.5	3	5	3	11
	4.0	36.2-36.9	3	5	3	11
	8.0	36.8-40.0	3	5	3	11

* All biopsies taken at 24 hours. See Table 2 for description of severity scores.

Burns produced by radiant thermal energy on rat skin were studied over a wide range of radiation intensities and exposure times. Some combinations of intensity and exposure time resulted in no detectable injury; others caused carbonization of the surface and complete coagulation of the skin and subcutaneous connective tissues. Many gradations between these extremes of severity were found and there was no indication of other than a gradual transition from one degree of severity to another. The first perceptible injury to the epidermis was manifest by swelling and vacuolization of the cytoplasm and the disappearance of nuclear structure. This amount of epidermal injury was accompanied by a mild inflammatory reaction in the dermis. At slightly higher energies, the epidermal-dermal cohesion was weakened and the epidermis slipped readily from the dermis. There was a massive inflammatory reaction of the dermis and a serous encrustation covered the surface of the lesion within a few hours. Still higher energy burns exhibited thin desiccated epidermal cells with markedly basophilic pyknotic nuclei, increasing amounts of dermal coagulation associated with a decreasing inflammatory reaction of the dermis, and a white to gray colored surface. The periphery of these lesions had the appearance of the milder burns. In the center of the most severe burns studied the epidermis was burned away, and the dermis was thin, completely coagulated, avascular and basophilic. Coagulation and basophilia extended through the panniculus carnosus. Here again the periphery of the burn area showed gradations of lessened severity.

The evidence of greater degrees of damage appeared first at the surface of the skin and then at progressively greater depths as the energy was raised.

The spectrum of tissue damage found in graded severity rat skin burns corresponds well with descriptions of injury reported for pig or guinea pig skin burns by Elman and Lischer (1), Leach, Peters, and Rossiter (2), and Moritz (3), even though the methods of application of heat varied considerably. This suggests that burn damage is not fundamentally related to the manner of application of heat energy. It is consistent with the thesis that the extent of injury to the tissue is a function of the temperature to which various portions of the tissue are raised and of the time during which the temperature is maintained. Histologically distinguishable tissue injury has been reported when a tissue temperature of around 44-45°C is maintained for a sufficient time (9). From the studies of Leach, Peters and Rossiter (2) it is evident that, within certain limits, increasing the tissue temperature produces a greater degree of tissue injury.

From the foregoing studies on the gross and histological changes accompanying radiant energy thermal burns, it is seen that the degree of tissue injury is related not only to the amount of energy delivered, but is also a function of the rate of energy delivery.

Consideration of the gross pathology of the burn lesion, as a function of energy delivered and delivery time, points up the variation in the amount of incident energy required to produce a specific type of damage as the rate of delivery is changed (Fig. 2). Clear cut differences are seen at the shorter times. The minimal energy which produced a gray lesion was 5 cal./cm.^{2}, 6.2 cal./cm.^{2} and 8.4 cal./cm.^{2} for 0.1, 0.2 and 0.4 seconds, respectively. Similar relations between threshold energy and exposure time were found for white and scaled lesions. At longer exposure times, 2 to 8 seconds, the differences were less pronounced. The reasons for the apparent trend, at longer exposure times, toward lessened dependence of the equi-effective energy values on exposure time are not entirely clear. One would expect the energy requirement to increase sharply when the delivery time was long enough that the incident energy could be dissipated by the body at a rate approaching the delivery rate.

Histological observation of several series of burns, each series produced by approximately equal amounts of energy delivered at differing rates, showed less damage when the exposure time was long, i.e., the delivery rate low. A grading system designed to provide a measure of both the relative total amount of damage sustained by the skin and the relative amount of damage sustained by each layer of the skin was devised. In each of the nine approximately equi-energy series studied no burn received a higher score than did a shorter exposure burn of the same series; and in 8 of the 9 groups, the longer burns were assigned lower scores. In the more severe burns of higher energy, the differences within an equi-energy series were less marked. This may be attributable to the fact that after a certain level of tissue damage is reached further variations in type of tissue change are not seen, and, as a result, differential grading of the severity of a burn lesion becomes more difficult than in the lower energy regions.

When burn lesions within each equi-energy series were compared, there was no case in which a lesion showing a greater degree of damage in the deep tissue was associated with a lesser damage in the more superficial tissues. In general there was a rough proportionality between the degree of superficial and deep damage.

SUMMARY

1. Burn lesions were produced by radiant energy, 3100^{0}A to 22000^{0}A, on depilated rat skin.

2. The gross and microscopic pathological changes so caused are described and correlated with the amounts of incident energy and the rate of energy delivery.

3. Within the limits studies, 0.2 to 64 cal./cm.^{2}/sec. and 0.1 to 8.0 seconds, it was found that increasing the rate of energy delivery lowered the amount of energy required to produce a specified degree of tissue injury.

4. The tissue changes were in many respects similar to those described for contact burns of the skin of rats and other animals.

5. The findings suggest the action of such intensities of this spectrum of radiant energy is essentially of a thermal nature.

Approved by:

M C Fishler

M. C. Fishler
Head, Biological and Medical
Sciences Division

For the Scientific Director

Acknowledgement

The authors wish to thank the Thermal Branch, Nucleonics Division, of the Naval Radiological Defense Laboratory for the development and operation of the thermal source used in the work described herein.

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