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STUDIES ON FLASH BURNS: THE INFLUENCE OF WAVE
LENGTH ON THE PRODUCTION OF CUTANEOUS BURNS

by:

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STUDIES ON FLASH BURNS:
 THE INFLUENCE OF WAVE LENGTH ON THE PRODUCTION OF CUTANEOUS BURNS
 BY
 KELLY M. BERKLEY, M. D., AND THOMAS P. DAVIS, B. S.

Abstract

The influence of the three general regions of the spectrum, ultra-violet, visible, and infrared on the production of cutaneous burns in swine at 0.5 and 1.0 sec exposure times was studied. The energy required to cause equivalent burns was compared region by region, and to that of the carbon arc source alone. Data was analyzed by a simplified method of probit analysis.)

It was found, in general, that the 50% effective dose of infrared radiation is significantly greater than that of the unmodified radiation of the carbon arc source. This difference is most marked at the erythema level. The type of erythema varied according to the presence or absence of ultraviolet radiation.

It is recommended that further investigation be made of the influence of wave length on the production of burns.

* * * * *

The medical problems resulting from atomic bomb explosions have stimulated the study of burns from a short pulse of high intensity radiant thermal energy. The spectrum of the thermal emission from an atomic bomb has been compared to that of the sun (4), but this spectrum probably changes during the course of the explosion and from one type of bomb to another.

The authors gratefully acknowledge the assistance of Dr. Herman E. Pearse, Department of Surgery, University of Rochester, School of Medicine and Dentistry, in the preparation of this paper, and Dr. Arthur M. Dutton, Statistics Section, University of Rochester, for the statistical analysis of the data.

Since there is a difference of absorption (2,5) by the skin of different wave lengths it becomes of some importance to know if this modifies their capacity to cause thermal burns.

The carbon arc searchlight which is used in the laboratory as a source of radiant thermal energy, has a spectrum not unlike that of an atomic explosion except for a higher ultraviolet content. In a previous study (1) the beam of the arc was modified by a Pyrex glass plate which was a part of a monitor system, which eliminates ultraviolet. This reduced the severity of the burns as judged by the surface appearance.

The present experiment was designed to compare the energy required to cause equivalent burns produced by radiation through filters transmitting in the spectral regions of the ultraviolet, the visible, and the infrared with that of the carbon arc source alone.

Equipment: The physical source of the radiant energy consists of an Army carbon arc searchlight, as described by Davis, Krolak and Blakney (3).

Three filters (Figure 1) provided wave length intervals in the infrared, visible and ultraviolet regions of the spectrum. Transmission curves are shown in Figure 2.

Infrared Radiation: This is obtained with a Corning sharp cut-off red filter, #2-58, which is mounted 5 1/4 inches from the plane of exposure. This filter transmits approximately 85% from 6600Å throughout the longer wave lengths, controlled to 10,000Å. With the carbon arc source, the maximum transmitted energy at the exposure plane is 14 cal/cm/sec.

4

Figure 1.

Figure 2. This graph shows the transmission curves of the three filters used. The ultraviolet filter and the infrared filter transmission measurements were made directly. The curve of the visible filter was synthesized.

The assistance of Mr. Richardson and Dr. Julian Webb of the Kodak Park Research Laboratory, who made all the transmission measurements, is gratefully acknowledged.

Visible Radiation: A combination of a filter and a glass cell 5 cm deep containing doubly distilled water was necessary to obtain this radiation. The filter selected, Corning glass #4784 polished to one half of standard thickness, transmits radiation in both the visible and infrared regions. The addition of the glass cell containing water eliminates the unwanted infrared transmission. Using this system, with the cell mounted 7 inches and the filter 5 1/4 inches from the exposure plane, the region from 3200 to 8000Å is defined. The transmission curve obtained by synthesis of spectrographic measurements is essentially an asymmetrical bell-shaped curve with a long decline from 6000 to 8000Å. However 50% transmission results from 3700 to 5840Å with a maximum of 69% at 5000 to 5500Å. The maximum energy transmitted by this system is 10 cal/cm²/sec.

Ultraviolet Radiation: To provide this radiation a Corning ultraviolet transmitting filter #7-54 is combined with a 60% (weight per volume) solution of NiSO₄·6H₂O to absorb wave lengths in the infrared region transmitted by the #7-54 filter. The solution is held in a 2 cm deep fused quartz cell with the #7-54 filter mounted behind the cell on a 1/16" spacer ring; the entire system is mounted 2 inches from the exposure plane. The transmission curve of this filter system is essentially bell-shaped with 0% transmission at 2200 and 3600Å and a maximum of 59% at 3000Å. The maximum energy transmitted is approximately 0.6 cal/cm²/sec and thus the filter is of limited usefulness. With exposures of one second, the solution boils; therefore the system is used only for one-half second exposures.

Methods: Chester White pigs weighing between 8.3 and 12.6 kg, anesthetized with Dial in urea-urethane (Ciba) given intraperitoneally in doses of 65 to 75 mg per kg body weight (6), are used as the experimental animal. The hair is closely clipped and the skin gently sponged and dried in preparation for burning.

Exposure times of one-half and one second are selected to form the following two experiments.

Experiment 1 (one-half second): Radiant exposures (a) of 2.0, 3.0, 3.5, 4.0, and 5.0 cal/cm² with visible radiation; 4.0, 5.0, 5.5, and 7.0 cal/cm² with infrared radiation; and 0.3 cal/cm² with ultraviolet radiation are given. There are then 10 combinations of quality and amount of applied radiant energy. Two of each combination are made on each side of six animals. The site selected for any combination is chosen by systematic randomization (b). Almost all the burns are biopsied.

Experiment 2 (one second): Twelve animals are used to give radiant exposures of 2.5, 3.0, 3.5, 4.0, 5.0, 6.0, 7.2, 8.0 and 10.0 cal/cm² of visible radiation and 3.5, 4.0, 4.6, 6.3, 7.3, 8.2, 9.0, 10.2, 11.6, and 14.0 cal/cm² of infrared radiation. This results in 18 combinations of which one combination is divided between 3.5 and 6.3 cal/cm² of infrared radiation. The filter transmitting ultraviolet radiation could not be used at this exposure time. By systematic randomization, the site is selected to produce one of each of the combinations on each side of 12 animals. Biopsies of lesions of six animals are made.

Evaluation: Burn severity is assessed 24 hours after exposure by the method previously described (9). A summary of these criteria follows:

<u>Laboratory Grade</u>	<u>Surface Appearance</u>	<u>Descriptive Term</u>
1+	Erythema	Red Burn
2+	Patchy Coagulation	Spotted White Burn
3+	Uniform Coagulation	White Burn
4+	Steam Bleb	Blebbled White Burn
5+	Carbonization	Charred Burn

(a) Radiant exposure equals the radiant energy per unit area which falls on a surface during a given time interval.

(b) By this method there is an equal probability of any combination falling in any position on any animal.

Biopsy sections through the center of the lesion are taken at the time of evaluation of surface appearance, fixed in Bouin's solution, and stained by hemotoxylin and eosin. Microscopic evaluation is based on the scale previously proposed (9) but evaluation of damage in the dermis deviates from the previous method as follows: the depth of damage is assayed from the surface vertically to a line of demarcation between altered and unaltered tissue without regard to the line of demarcation of viable and non-viable epithelium along the hair follicles. A micrometer scale in the ocular of the microscope aids this determination.

The criterion chosen for comparison of 50% effective doses is complete transepidermal necrosis, at which point the epidermal cells are grossly distorted and detached from the underlying unaltered dermis. Figure 3 is a photomicrograph of this burn.

The 50% effective doses and 95% confidence intervals are computed by the approximate probit analysis method of Litchfield, J. T., Jr. and Wilcoxon, F. (7).

Results: The data from evaluation of the surface appearance of the burn lesions are compiled in Table 1 for Experiment 1 and in Table 2 for Experiment 2. The source and radiant exposure in cal/cm² appear in the first two columns. The middle section contains the number of burns produced at each criterion of severity. The figure in parenthesis denotes the percentage of the total number of exposures at a given combination. The 50% effective doses (ED₅₀) with 95% confidence intervals appear in the Tables 1a and 2a.

In one-half second exposures, 50% effective doses were found for 1+, 2+ and 3+ burns produced by visible radiation, but with infrared radiation these values could be determined for 1+ and 2+ burns only. In one second exposures, 50% effective doses could be determined for 1+, 2+ and 3+ burns produced both by visible and infrared radiation. Radiant exposures of ultraviolet radiation are limited to 0.3 cal/cm² so only 1+ burns could be studied.

Data for the unmodified arc source at one-half second (unpublished) and at one second (9) are summarized below (Table 3).

Figure 3. This photomicrograph of a cross-section of burned skin depicts the separation of the epidermis from the underlying dermis which criterion is designated complete transepidermal necrosis. The dermis is uninvolved.

Table 1

Experiment 1. (Exposure Time: 0.5 Sec)

Results of Evaluation of Surface Appearance

Source	Radiant Exposure (cal/cm ²)	No Burn	Erythema	Patchy Coagulation	Uniform Coagulation	Total No. of Exposures
		0	1+	2+	3+	
Visible Radiation	2.0	18 (72%)	7 (28%)			25
	3.0	3 (13%)	19 (83%)	1 (4%)		23
	3.5	1 (5%)	11 (55%)	7 (35%)	1 (5%)	20
	4.0		13 (48%)	11 (41%)	3 (11%)	27
	5.0		1 (4%)	9 (38%)	14 (58%)	24
Infrared Radiation	4.0	7 (30%)	16 (70%)			23
	5.0	1 (4%)	21 (92%)	1 (4%)		23
	5.5	1 (4%)	16 (67%)	7 (29%)		24
	7.0		4 (16%)	14 (56%)	7 (28%)	25
Ultra-violet Radiation	0.3		23 (96%)	1 (4%)		24

Table 1a

Source	Laboratory Grade	50 Per Cent Effective Dose (cal/cm ²)	0.95 Confidence Interval (cal/cm ²)
Visible Radiation	1+	2.5	2.2-2.8
	2+	3.8	3.5-4.1
	3+	4.8	4.3-5.3
Infrared Radiation	1+	3.6	3.2-4.0
	2+	5.9	5.5-6.3

Table 2

Experiment 1. (Exposure Time: 1.0 Sec)

Results of Evaluation of Surface Appearance

Source	Radiant Exposure (cal/cm ²)	No Burn	Erythema	Patchy Coagulation	Uniform Coagulation	Steam Bleb	Total No. of Exposures
		0	1+	2+	3+	4+	
Visible Radiation	2.5	17 (71%)	7 (29%)				24
	3.0	8 (33%)	16 (67%)				24
	3.5	2 (9%)	17 (74%)	4 (17%)			23
	4.0	2 (8%)	14 (58%)	8 (33%)			24
	5.0		6 (29%)	15 (71%)			21
	6.0		1 (4%)	5 (22%)	17 (74%)		23
	7.2			3 (12%)	21 (88%)		24
	8.0		1 (4%)	1 (4%)	21 (91%)		23
	10.0				17 (74%)	6 (26%)	23
Infrared Radiation	3.5	11 (100%)					11
	4.0	17 (71%)	7 (29%)				24
	4.6	7 (29%)	17 (71%)				24
	6.3		4 (33%)	8 (67%)			12
	7.3		2 (9%)	19 (86%)	1 (5%)		22
	8.2	1 (4%)	0	9 (39%)	13 (57%)		23
	9.0		1 (4%)	3 (13%)	20 (83%)		24
	10.2			3 (12%)	22 (88%)		25
	11.6			1 (4%)	23 (96%)		24
	14.0				23 (96%)	1 (4%)	24

12

Table 2a

Source	Grade	50 Per Cent Effective Dose (cal/cm ²)	0.95 Confidence Interval (cal/cm ²)
Visible Radiation	1+	2.8	2.6-3.1
	2+	4.4	3.7-5.1
	3+	5.6	4.3-7.3
Infrared Radiation	1+	4.3	4.1-4.6
	2+	5.4	4.5-6.5
	3+	8.3	7.5-9.0

Table 3

The ED₅₀ and 95% Confidence Intervals of Burns
from Unmodified Arc Radiation

Laboratory Grade	Time (sec)	50 Per Cent Effective Dose (cal/cm ²)	0.95 Confidence Interval (cal/cm ²)
1+	0.5	1.4	1.1-1.7
2+	0.5	3.2	2.9-3.5
3+	0.5	5.1	4.5-5.7
1+	1.0	1.4	1.1-1.6
2+	1.0	4.3	3.9-4.8
3+	1.0	7.0	6.6-7.4

Figure 4 relates the 50% effective doses and 95% confidence intervals produced by visible and infrared radiation at 0.5 sec at each level of burn severity obtainable in Experiment 1, and compared to those of the carbon arc source alone (unmodified radiation). The 50% effective doses of infrared radiation burns are significantly higher at this level of confidence than those of visible and unmodified radiation. The 50% effective doses of visible radiation burns are significantly higher than those of unmodified radiation for 1+ burns but not for 2+ and 3+ burns.

Figure 5 shows the relationship of 50% effective doses and 95% confidence intervals of unmodified, visible, and infrared radiation burns at 1.0 sec (Experiment 2). The 50% effective doses of infrared radiation are significantly higher at this level of confidence than those of unmodified and visible radiation burns of grade 1+ and 3+ but not 2+. The 50% effective doses of visible radiation burns are significantly higher than those of unmodified radiation burns at 1+ but not 2+ and 3+. The latter relationship was also seen in Experiment 1.

Figure 4. This graph shows the comparison of the 50% effective doses of unmodified, visible and infrared radiation of 1+, 2+, and 3+ burns at 0.5 sec exposures (Experiment 1).

Figure 5. This graph shows the comparison of the 50% effective doses of unmodified, visible and infrared radiation of 1+, 2+, and 3+ burns at 1.0 sec exposures (Experiment 2).

In both experiments for grade 1+ burns the 50% effective doses for visible radiation burns and for infrared radiation burns increase approximately two and three fold respectively in comparison to the unmodified source. From Table 1, it is to be noted that 0.3 cal/cm^2 of ultraviolet radiation produced erythema (grade 1+) in 96% of 24 exposures in comparison to 50% effective doses of 1.4, 2.5 and 3.6 cal/cm^2 for the unmodified, visible and infrared radiation respectively.

There is a qualitative difference in the appearance of lesions graded 1+, however. The erythema of visible and infrared radiation appears as tiny spots of red of moderate intensity in the center of the exposed area. These spots grew in intensity and persisted from 24 to 36 hours. The erythema of ultraviolet and unmodified radiation is uniform over the 1.7 cm area and disappears shortly after exposure to reappear in about six hours to persist for 24 to 36 hours. It would appear then, that a different mechanism of erythema production is acting with radiation sources containing wave lengths in the ultraviolet spectrum.

Tables 4 and 5 summarize the results of evaluation of the depth of damage of the burns at 0.5 and 1.0 sec respectively. The source and the radiant exposure in cal/cm^2 appear in the first two columns. The middle section shows the number and percentage of the total number of burns examined at each criterion of severity for the stated conditions.

The 50% effective doses and 95% confidence intervals are given in Tables 4a and 5b. The 50% effective doses and 95% confidence intervals for complete transepidermal necrosis produced by the unmodified source at 0.5 (unpublished) and 1.0 sec (9) are given below (Table 6).

Table 4

Experiment 1. (Exposure Time: 0.5 Sec)

Results of Evaluation of Depth of Damage (Microscopic)

Source	Radiant Exposure (cal/cm ²)	No Burn 0	Epidermal Acidophilism		Transepidermal Necrosis		Dermal Damage			No. of Exposures Examined
			Part of Depth	All of Depth	Focal	Complete	Superficial	Mid	Deep	
Visible Radiation	2.0	1 (25%)		3 (75%)						4
	3.0		3 (17%)	13 (72%)		2 (11%)				18
	3.5		1 (6%)	13 (72%)	2 (11%)	2 (11%)				18
	4.0		1 (4%)	16 (67%)	3 (13%)	2 (8%)	2 (8%)			24
	5.0			1 (4%)	1 (4%)	8 (34%)	7 (29%)	7 (29%)	0	24
Infrared Radiation	4.0	2 (12%)	3 (19%)	11 (69%)						16
	5.0			23 (100%)						23
	5.5			23 (96%)		1 (4%)				24
	7.0			10 (44%)	7 (30%)	3 (13%)	2 (9%)	1 (4%)	0	23
Ultra-violet Radiation	0.3		14 (61%)	9 (39%)						23

18

Table 4a

Source	Grade	50 Per Cent Effective Dose (cal/cm ²)	0.95 Confidence Interval (cal/cm ²)
Visible Radiation	Complete Transepidermal Necrosis	4.4	4.0-4.9
Infrared Radiation		8.1	7.1-9.3

18

4.6

19
Table 5

Experiment 2. (Exposure Time: 1.0 Sec)

Results of Evaluation of Depth of Damage (Microscopic)

Source	Radiant Exposure (cal/cm ²)	Epidermal Acidophilism		Transepidermal Necrosis		Dermal Damage			No. of Exposures Examined
		Part of Depth	All of Depth	Focal	Complete	Superficial	Mid	Deep	
Visible Radiation	2.5	1 (33%)	2 (67%)						3
	3.0	3 (50%)	1 (17%)	1 (17%)	1 (17%)				6
	3.5	5 (63%)	1 (12%)	2 (25%)					8
	4.0	4 (36%)	2 (18%)	4 (36%)	1 (9%)				11
	5.0	1 (8%)	1 (8%)	8 (61%)	3 (23%)				13
	6.0				5 (45%)	6 (55%)			11
	7.2				2 (20%)	7 (70%)	1 (10%)		10
	8.0					8 (67%)	4 (33%)		12
	10.0					4 (36%)	5 (46%)	2 (12%)	11
Infrared Radiation	3.5	1 (100%)							1
	4.0		1 (50%)	1 (50%)					2
	4.6	3 (50%)	2 (33%)		1 (16%)				6
	7.3	1 (10%)	1 (10%)	5 (50%)	3 (30%)				10
	8.2				4 (40%)	6 (60%)			10
	9.0					7 (50%)	6 (50%)		12
	10.2					5 (39%)	7 (53%)		13
	11.6				1 (8%)	4 (33%)	8 (67%)		12
	14.0					4 (33%)	6 (50%)	2 (17%)	12

20

Table 5a

Source	Grade	50 Per Cent Effective Dose (cal/cm ²)	0.95 Confidence Interval (cal/cm ²)
Visible Radiation	Complete Transepidermal Necrosis	5.3	4.5-6.1
Infrared Radiation		7.3	6.1-8.8

Table 6

The 50% Effective Dose and 0.95 Confidence Interval for Complete Transepidermal Necrosis Produced by the Unmodified Source

Time (Sec)	50% Effective Dose (cal/cm ²)	0.95 Confidence Interval (cal/cm ²)
0.5	4.6	3.8-5.6
1.0	4.6	3.6-6.1

Figure 6 shows the relationship of the 50% effective doses and 95% confidence intervals of complete transepidermal necrosis for infrared, visible and unmodified radiation for both experiments 1 and 2. The 50% effective dose of infrared radiation at 0.5 sec is significantly higher than those of unmodified or visible radiation. The 50% effective doses of visible and unmodified radiation are not significantly different. At 1.0 sec no significant difference is noted in the 50% effective doses for the three types of radiation.

It was noted previously that the surface appearance of 1+ burns produced by radiation containing ultraviolet differs from that of the visible and infrared radiation.

The depth of damage at the erythema level also varies. Table 7 shows the results of microscopic evaluation of 1+ burns produced at 0.5 sec. In this table the figures without and with parenthesis designate the number and percentage of burns observed at the criterion indicated.

Figure 6. This graph shows the comparison of the 50% effective doses of unmodified, visible and infrared radiation of complete transepidermal necrosis at both 0.5 and 1.0 sec.

Table 7

Results of Microscopic Evaluation of 1+ Burns Produced at 0.5 Sec

Source	Epidermal Acidophilism		Transepidermal Necrosis		Total No. of Lesions Examined
	Part of Depth	All of Depth	Focal	Complete	
Visible Radiation	4 (8%)	24 (47%)	4 (8%)	5 (10%)	37
Infrared Radiation	3 (5%)	39 (68%)	7 (12%)	2 (4%)	51
Ultraviolet Radiation	14 (61%)	9 (39%)			23

Only part of the depth of the epidermis shows acidophilism in 61% of 1+ burns produced by ultraviolet radiation, whereas only a small percentage of 1+ burns produced by visible and infrared radiation show such a small amount of damage. Furthermore, there are no 1+ burns produced by ultraviolet radiation which show transepidermal necrosis, whereas 18% and 16% of those produced by visible and infrared radiation respectively show this amount of damage.

At the erythematous level, then, the depth of damage is less for ultraviolet radiation burns than for infrared and visible radiation burns. This is evidence to indicate that with visible and infrared radiation, all the depth of epidermal cells must be altered, to allow the capillaries in the subpapillary layer of the skin to be affected directly to produce a fixed red reaction. However, with ultraviolet radiation, the epidermal cells are altered incompletely in depth, but erythema of a transient nature results.

In summary, the results of the effect of the radiation of the unmodified carbon arc source and that transmitted by the three filters on the production of cutaneous burns are:

1. In all instances of evaluation by surface appearance except for 2+ burns at 1.0 sec, the 50% effective dose required is significantly greater for infrared radiation than for visible or unmodified radiation.
2. With burns of 1+ severity, the 50% effective doses increase progressively for unmodified, visible, and infrared radiation. However, the resultant lesion of erythema is not strictly comparable. The surface appearances are different, and the depth of damage varies.

3. With burns of 2+ and 3+ severity, there is no significant difference in the 50% effective doses of visible and unmodified radiation.

4. The 50% effective dose of infrared radiation for complete transepidermal necrosis is also significantly higher than that of unmodified or visible radiation at 0.5 sec, but not at 1.0 sec.

DISCUSSION: Comparison of the infrared radiation and the unmodified radiation can be made without further qualification. This is not true, however, with comparisons involving the visible or ultraviolet radiation, since the rather long optical path of the filters transmitting visible or ultraviolet radiation causes aberrations in the beam of radiant energy which may produce a more uniform distribution of energy over the exposure plane than that which exists with unmodified or infrared radiation. This variation in the distribution of energy may alter the 50% effective doses.

CONCLUSIONS: 1. The 50% effective dose of infrared radiation is, in general, greater than that of the unmodified radiation of the carbon arc source. This difference is most marked at the erythema level, at which the ratio of the 50% effective dose of infrared radiation to the 50% effective dose of unmodified radiation is about 2.6. For 2+ and 3+ burns the ratio is nearly 1.5, while for transepidermal necrosis the ratio is about 1.7.

2. Erythema produced by sources containing ultraviolet radiation is uniform, disappears in one-half hour, and reappears in 6 hours to persist for 24 to 36 hours. Erythema produced by sources lacking ultraviolet radiation is spotty and persistent.

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