UR-418

A COMPARISON OF THE EFFECTS ON BARE PORCINE SKIN OF RADIANT ENERGY
DELIVERED IN THE FORMS OF SQUARE AND SIMULATED FIELD PULSES

by

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ATOMIC ENERGY PROJECT
ROCHESTER, NEW YORK

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UR-418

Health and Biology

THE UNIVERSITY OF ROCHESTER
Atomic Energy Project
P. O. Box 287, Station 3
Rochester 20, New York

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Contract W-7401-eng-49 between the U. S. Atomic
Energy Commission and the University of Rochester,
administered by the Department of Radiation Biology
of the School of Medicine and Dentistry.

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Date Completed: 11/29/55

Date of Issue: 12/21/55

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ABSTRACT

The critical energy required to produce a 2+ burn in the Chester White pig has been used as a method of comparing the effectiveness of radiant energy delivered in the forms of "square pulses" and "simulated field pulses." With both types of pulse, increasing the time of exposure necessitates an increase in the total energy delivered in order to produce a 2+ burn. There is no significant difference between the scaling factors for the two types of pulse.

INTRODUCTION

In a previous report Mixer (1) proposed the following equation for the 50% effective radiant exposure required to produce a 2+ burn on Chester White pigs:

$$Q_c = 4.4 t^{0.22}$$

where Q_c = critical energy of 50% effective radiant exposure for a 2+ burn (cal/cm²) and

t = time of exposure (sec).

This equation was derived by combining the data presented in earlier reports (2, 3) with the results of some work on 50% effective radiant exposures at longer times. After a redetermination of source output and inclusion of later data, this equation was changed to:

$$Q_c = 3.7 t^{0.23} \quad (1)$$

In a subsequent report (5) Mixer combined his data on the simulated field pulse and found that the median effective exposure for a 2+ burn could be expressed by a similar equation. This can be written:

$$Q = 3.9 t^{0.14} \quad (2)$$

where t is the duration of the simulated field pulse in seconds.

Although it was pointed out by Henriques (6) that the scaling factor, i.e., the exponent on t in equations (1) and (2) above, should be independent of pulse shape, a statistical analysis of the data leading to the above two equations indicated that the two scaling factors were, indeed, not equal at the 99% level of confidence. However, these factors had been obtained from several experiments extending over a considerable length of time; hence, no precise statement regarding their inequality could properly be made. Therefore it was thought necessary to compare directly in a single experiment the effects of these two types of pulse to determine whether or not this difference in scaling factors was real.

METHODS

Experimental

The experimental design selected was a simple randomized block in which square pulses of 0.3, 3.0, and 30 second duration and simulated field pulses of 1.27, 4.0, 12.65, and 40 second duration were compared. At each of these exposures five irradiances, uniformly separated by 10% increments, were used. (At some of the exposure times additional irradiances were necessary.) These 35 treatments were randomly assigned to 35 exposure areas on the side of an experimental animal, and this treatment block was replicated 16 times, giving a total of 560 exposures.

The animals used were Chester White pigs weighing 8-12 kilograms and anesthetized with intraperitoneal Dial in Urea-urethane (Ciba) in doses of 75 mgm/Kg. of body weight. The hair was removed with electric clippers and the skin was washed. To lessen the variation in skin temperature, the ambient temperature of the room was controlled during burning. The burns were assessed 18-24 hours following burning by the criteria previously reported (2, 3, 7).

The heat source was a modified 24 inch Army carbon arc searchlight (8) with certain modifications previously described (7). The field pulse was simulated by interposing a rotating, slotted wheel between the source and the port (9). This wheel "amputates" the tail of the pulse so that only the first 88% of the "weapon energy" is delivered, but this loss does not affect the surface evaluation of the burns (10).

Analysis

A scaling equation, such as the two given above, may be written in general as:

$$Q_c = A t^{\alpha} \quad (3)$$

where Q_c is the median effective radiant exposure for the particular response desired, t is the exposure time, A is the value of Q_c where t is equal to unity, and α is the experimentally determined scaling factor. Since A and α are invariant for any given pulse shape, one may write:

$$\frac{Q_c(t_1)}{Q_c(t_2)} = \left(\frac{t_1}{t_2}\right)^\alpha$$

where $Q_c(t_1)$ is the median effective exposure at exposure time t_1 and $Q_c(t_2)$ is that at exposure time t_2 .

A ratio of two median effective exposures is defined as a potency ratio, P. R., and one may write:

$$P. R. (t_1, t_2) = \frac{Q_c(t_1)}{Q_c(t_2)} = \left(\frac{t_1}{t_2}\right)^\alpha \quad (4)$$

Taking the logarithm of both sides of this equation one obtains:

$$\alpha(t_1, t_2) = \frac{\log [P. R. (t_1, t_2)]}{\log (t_1/t_2)} = \frac{\log Q_c(t_1)/Q_c(t_2)}{\log (t_1/t_2)} \quad (5)$$

where the terminology is obvious.

The stated purpose of this experiment is to compare the scaling factors for square and simulated field pulses, but the design also permits testing of the adequacy of a simple scaling equation, such as (3) above, to define accurately the isoresponse curve. Thus, one may formulate the null hypothesis as:

$$\begin{aligned} H_0 \quad (a) \quad \alpha(3.0, 0.3)_s &= \alpha(30, 3.0)_s, \\ (b) \quad \alpha(12.65, 1.27)_f &= \alpha(40, 4.0)_f, \\ (c) \quad \alpha(3.0, 0.3)_s &= \alpha(12.65, 1.27)_f, \\ (d) \quad \alpha(3.0, 0.3)_s &= \alpha(40, 4.0)_f, \\ (e) \quad \alpha(30, 3.0)_s &= \alpha(12.65, 1.27)_f, \\ (f) \quad \alpha(30, 3.0)_s &= \alpha(40, 4.0)_f \end{aligned}$$

where the subscripts s and f indicate square and simulated field pulses respectively. Equations (a) and (b) test the ancillary hypothesis covering the adequacy of the scaling equation over the indicated exposure time interval, while the remainder of the equations test the hypothesis that the scaling factor for square and simulated field pulses is the same.

It will be noted that in all cases above the scaling factors involve exposure times which are in the ratio of ten to one. Thus, from equation (5) it is clear that one may test the null hypothesis above by comparing not the scaling factors themselves but rather the associated potency ratios. The null hypothesis may then be rewritten:

$$\begin{aligned} H_0': \quad (a') \quad P. R. (3.0, 0.3)_s &= P. R. (30, 3.0)_s, \\ (b') \quad P. R. (12.65, 1.27)_f &= P. R. (40, 4.0)_f, \\ (c') \quad P. R. (3.0, 0.3)_s &= P. R. (12.65, 1.27)_f, \end{aligned}$$

and so forth.

It must be pointed out that the six equations of the null hypothesis are not independent, and it is neither the meaning nor the intent of the statement to test these equations jointly.

The exposure-response data obtained were analysed by the method of Litchfield and Wilcoxon (11) to obtain estimates of median effective exposures and potency ratios, and of the 95% confidence limits thereon. Each equality (a') through (f') was rejected if the estimated confidence intervals of the two potency ratios involved did not overlap. It may be noted that the simplified method of analysis employed almost always yields confidence interval estimates larger than a rigorous probit analysis; this will have the effect of increasing the level of confidence above the stated 95%, which is not undesirable.

RESULTS

The data obtained from gross assessment of the burns are presented in Tables I and II. From these data the median effective exposures (Q_c 's) have been calculated, and the results are shown in Table III. Fig. I is a logarithmic plot of the isoresponse curves with the exposure time as the abscissa and radiant exposure as the ordinate. The 95% confidence limits are indicated by **I** symbols.

By the method of analysis previously cited (11) the point and 95% confidence interval estimates of the potency ratios were determined (Table IV). There is overlap of the confidence intervals in all cases, so the six equalities of the null hypothesis are not rejected at the 95% level of confidence. A single estimate of the scaling factor, α , was then obtained from a pooled estimate of the potency ratios. A simple arithmetic mean of the potency ratios yields a value of:

$$\alpha = 0.15 \text{ sec.}^{-1}$$

DISCUSSION

Data presented in two previous reports (1, 5) suggested a difference in scaling factors for square and simulated field pulses. The scaling factor derived from our data is similar to the factor derived from earlier work with simulated field pulses (5) and differs significantly from the factor suggested for square pulses (1, 4). This difference may be due to the fact that the earlier square pulse scaling equation was derived from insufficient data for exposure times longer than three seconds. In this work, which was designed to compare the two pulses directly, no such difference has been found in the scaling factors for the $2+ EE_{50}$ for bare skin burns.

TABLE I
BURNS PRODUCED BY RADIANT ENERGY DELIVERED
IN THE FORM OF A SQUARE PULSE

Time (Sec)	Q (Cal/cm ²)	0	1+		2+			3+
			Mild	Sev.	Mild	Mod.	Sev.	
0.3	3.85				5	4	4	
	3.46		2	5	2	5	2	
	3.11		5	5	5	1		
	2.80		9	4	3			
	2.52		2	1				
3.0	5.76				2	5	4	5
	5.19				8	4	2	2
	4.68			1	9	1	4	1
	4.20		3	5	6	2		
	3.78		6	7	3			
30.0	9.61							3
	8.67			1	1	1	2	3
	7.80		1	3	0	3	4	5
	7.02		1	1	7	3	3	1
	6.30	1	2	1	8	3	1	
	5.67		4	5	4			
	5.10		6	2				

TABLE II
BURNS PRODUCED BY RADIANT ENERGY DELIVERED IN
THE FORM OF A SIMULATED FIELD PULSE

Time (Sec)	Q* (Cal/cm ²)	0	1+		2+			3+
			Mild	Sev.	Mild	Mod.	Sev.	
1.27	5.11				2	2	8	3
	4.60			1	2	7	4	2
	4.14			2	8	3	2	1
	3.72		1	8	4	3		
	3.35		4	7	3	1		
4.0	5.63					8	5	3
	5.07				9	4	2	1
	4.56			6	6	3	1	
	4.11		2	6	7		1	
	3.70		4	6	2	1		
12.65	6.89			1	1	3	5	6
	6.21		1	1	5	4	3	2
	5.58			2	5	4	4	1
	5.04		3	6	5		2	
	4.52		7	7	2			
40.0	8.48				1			2
	7.59			2	3	4	3	4
	6.84			2	6	4	3	1
	6.16		2	4	5	4		1
	5.54		9	4	1	1	1	
	4.99		7	5	1			

*Radiant energy actually delivered.

TABLE III

MEDIAN EFFECTIVE EXPOSURE (EE_{50}) FOR EACH EXPOSURE TIME

Time (Sec)	Type of Pulse	EE_{50} (cal/cm ²)	Confidence Limits
0.3	Square	3.3	3.0 - 3.6
3.0	Square	4.2	4.0 - 4.4
30.0	Square	6.3	5.8 - 6.8
1.27	Simulated Field Pulse	3.6	3.4 - 3.9
4.0	Simulated Field Pulse	4.2	3.9 - 4.5
12.65	Simulated Field Pulse	5.2	4.7 - 5.7
40.0	Simulated Field Pulse	6.4	6.0 - 6.8

TABLE IV

Pulse Shape	Exposure Times		Potency Ratio	
	t_1	t_2	Point Estimate	C. I. Estimate
Square	3.0	0.3	1.3	1.14 - 1.38
Square	30.0	3.0	1.5	1.36 - 1.65
Field	12.65	1.27	1.4	1.27 - 1.60
Field	40.0	4.0	1.5	1.36 - 1.68

Figure I. The median effective exposures are plotted on a logarithmic scale. Solid $\bar{\text{I}}$ symbols represent the confidence limits of the simulated field pulse, and a solid line is drawn through these. Broken $\bar{\text{I}}$ symbols and line represent the square pulse.

One cannot say that in other conditions, when the skin is not bare or when the damage is not centered around the 2+ burn, the degree of damage from the two types of pulse is not significantly different. To be perfectly certain that there is or is not a difference in the effects of the two types of pulse, both pulses would have to be used for each set of experimental conditions. Nevertheless, a significant difference which was once thought to exist between the square and simulated field pulses has not been confirmed.

It is interesting to observe that the greatest disparities between potency ratios were not between those for pulses of different shape, but rather between those for the extremes of exposure time intervals. While these disparities were not sufficiently large to lead to a rejection of the hypothesis of equality, at the 95% level of confidence, one may still argue that the data indicate that a simple scaling law such as equation (3) may not be adequate to define the isoresponse curve over such an extended range of exposure times.

Finally, it is noteworthy that the experience of this laboratory has been that supposedly identical treatments in different experiments may well produce significantly different median effective exposures. Hence it is probable that no scaling law, no matter how complex, can provide more than qualitative predictions of isoresponse curves. A natural corollary of this is that every experiment must contain its own control in order that meaningful statements of treatment effects may be made.

SUMMARY AND CONCLUSIONS

1. The $2+ EE_{50}$ for square pulses of 0.3, 3.0, and 30.0 second durations have been compared directly with the EE_{50} of simulated field pulses of 1.27, 4.0, 12.65, and 40 seconds.
2. Assuming a scaling law of $Q_c = A t^\alpha$, no significant difference was found in the scaling factors for the two types of pulse investigated.
3. The average scaling factor for the pulses and exposure times studied was estimated as $\alpha = 0.15 \text{ sec.}^{-1}$.

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