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PRODUCTION OF LARGE AREA FLASH BURNS ON PIG SKIN

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ABSTRACT

A heat source employing burning magnesium flash powder in various charges and distances from the subject was studied for its ability to inflict reproducible large area burns on swine. Incident radiant thermal energy for each powder charge and each distance was measured with a cone calorimeter and found to be consistent for each combination. The burns produced by each of these combinations were assessed both for surface appearance and microscopic measurement of depth of damage. By both methods of grading each charge-distance combination gave uniform, reproducible burns. It was concluded that this source provides a dependable and useful tool for the laboratory study of large area flash burns.

INTRODUCTION

The production of flash burns in the laboratory requires a radiant heat source which is capable of delivering a specified amount of energy with minimal variance. The carbon arc (1) has proved to be a most valuable tool for this. However, the carbon arc produces high intensities of energy only at the focal plane of the system where a relatively small circle is uniformly irradiated. If a large area is to be burned the animal must be placed out of the focal plane, in which case less energy is applied. Similarly, if a protective device is to be tested at a distance from an animal, there is no way of placing both screen and animal in the focal plane. A source free of these two limitations is necessary if large area lesions are to be studied. The burns from such a source must be predictable and reproducible.

Pearse, Payne, and Hogg (2), in 1949, explored a number of possible energy sources suitable for laboratory use and concluded that the carbon arc and magnesium flash powder were the two most satisfactory. Since then the magnesium source has been under study in this laboratory and has recently been described in its present state of development (3).

In the following experiments the magnesium source and the burns produced have been studied to obtain basic information for use in designing future experiments. It was desired to know the reproducibility of the lesions and the effects of modifying both the amount of magnesium and its distance from the test object.

METHODS

Young Chester White pigs weighing from 8 - 12 Kg were anesthetized with intraperitoneal Dial-urethane (Ciba) in doses of 70 mg/Kg. The hair of both sides was closely clipped and the skin gently sponged with detergent in water.

The method of burning magnesium recently described by Roth et al. (3) was followed with the anesthetized animal placed behind a 2 inch exposure port. Three charges of magnesium, 50 gm., 100 gm., and 150 gm., were ignited at 15 cm., 30 cm., and 45 cm. from the pig's side. These nine charge-distance combinations were assigned by a random plan to the sides of each animal and ten replications were performed giving a total of 90 burns.

Davis (4) has developed a nickel cone calorimeter which, for the first time, makes it possible to measure the incident radiant energy from the magnesium flash with accuracy. Each exposure, with the exception of the 150 gm. at 15 cm. combination, was monitored by placing the calorimeter at a point equal to the tray-skin distance to measure the cal/cm² of radiant energy. The 150 gm. - 15 cm. combination proved to be too close to the flame for accurate measurement with this equipment.

The ignited magnesium produced a symmetrical sheet of flame lasting about 0.7 second.

All burns were assessed by their surface characteristics 18 - 24 hours after infliction according to the criteria established in this laboratory (5). These criteria are summarized as:

- 0 - No burn
- 1+ - Erythema
- 2+ - Patchy whiteness
- 3+ - Uniform whiteness
- 4+ - Steam bleb
- 5+ - Charring

Biopsies of the last four replications were taken at the time of surface reading and fixed in 10% formalin. These specimens were stained by the method of Hinshaw (6) which has the ability to differentiate the depth of the dermal burn. Damage was measured by a micrometer in the eyepiece of the microscope at the deepest point observed on the section.

RESULTS

Calorimetry

The mean incident radiant thermal energy in cal/cm² has been computed for each charge-distance combination. The variance - σ^2 - for each has been determined. Both determinations are listed on the right-hand side of Table I. The acceptable variance in each case indicates uniformity of the charges. However, at 30 and 45 cm. the variances are all smaller, and the use of the two lesser charges at these distances delivers the most constant incident energy. If the mean energy is plotted against the tray distance for each charge of magnesium a family of curves is obtained (Fig. 1).

Surface Appearance of Burns

The exposed 2 inch circles of skin were, for the most part, burned uniformly. Where more than one degree was seen on the same burn the more severe grade was used for assessment. Each burn is listed according to surface grade on the left side of Table I, where it is seen that each exposure combination gave good reproducibility. The edges of burn damage were sharply defined but shortly after exposure there developed a flush surrounding the more severe burns; this had only partially faded in 24 hours.

At the 15 cm. distance with 50 gm. of magnesium, 50% of the burns had large steam blebs and 50% had varying amounts of carbonization usually representing burst blebs with charred edges. At this same distance 100 gm. and 150 gm. gave burns which were leather-like and more uniformly charred.

At 30 cm. a 50 gm. charge always produced a uniform 3+ burn. Both 100 gm. and 150 gm. here gave a majority of 4+ burns with a lesser number showing areas of carbonization.

TABLE I
EXPERIMENTAL RESULTS BASED ON SURFACE GRADE

Tray-Skin Distance in cm.	Magnesium Charge in Grams	Number of Burns and Surface Grade					Mean Inci- dent Energy (cal/cm ²)	Variance σ^2
		1+	2+	3+	4+	5+		
15	50				5	5	11.4	2.09
	100					10	21.4	3.74
	150					10	-	-
30	50			10			4.8	0.07
	100				7	3	10.2	0.35
	150				6	4	13.5	1.28
45	50	4	6				2.6	0.06
	100			10			5.3	0.06
	150			1	6	3	7.6	1.26

Figure 1.

Radiant Exposure vs. Distance for Each Charge of Magnesium Powder

When the distance was increased to 45 cm. and a charge of 50 gms. of magnesium was used, 40% of the burns were 1+ and 60% were 2+ in severity. At this distance 100 gms. always gave uniform 3+ burns identical in surface appearance to the burns of 50 gms. at 30 cm. Increasing the charge to 150 gms. at the 45 cm. distance changed the distribution to 60% 4+ burns with 30% of the burns showing areas of char. This is similar to the results with 100 gms., and 150 gms. at 30 cm.

If the incident energy is compared to surface grade it will be seen that 2.6 cal/cm² gave a 1+ - 2+ split; that 4.8 and 5.3 cal/cm² both inflicted 100% 3+ burns; and that the range for a 4+ - 5+ split varied from 7.6 cal/cm² to 13.5 cal/cm². This relationship is shown graphically in Fig. 2 where the ordinate expresses cal/cm² and the abscissa the surface grade.

Microscopic Evaluation

Hogg, Payne and Pearse (7) have previously described the microscopic changes occurring in magnesium flash burns. In milder burns the damage is usually confined to the epithelium where alterations of staining characteristics, nuclear pyknosis and cellular flattening are seen. The dermal-epidermal junction is frequently involved in even the mildest burns. Here one may see all stages of tonofibrillary stretching to the point of rupture, and filling of this potential space with edema fluid so that the epidermis may be quite widely separated from the dermis. It would appear that this junction offers some barrier to heat flow since burns showing these rather marked superficial changes very often fail to have any dermal damage.

As the applied heat increases, the epidermis soon becomes completely destroyed and may become flattened against the dermis as amorphous debris. As damage progresses into the dermis, the collagen fibers are altered in

Figure 2

Surface Grade vs. Incident Radiant Energy

their staining characteristics and undergo a cellular flattening and nuclear pyknosis similar to the epidermis. The fibers at first show varying degrees of separation by edema fluid. However, as full thickness damage is approached, cellular detail becomes destroyed and there is a general shrinking of the dermal remnants.

In the pig, hair follicles may extend well into the subcutaneous fat. In most of the burns damage to the epithelial lining of the hair follicles extended deeper than any detectable dermal damage. As in partial epidermal damage, the junction between normal appearing and damaged cells in the hair follicles was very sharp. In some cases the limit of dermal damage was sharply defined although in other burns damaged collagen fibers were mixed with normal appearing tissue.

Table II summarizes these characteristics for each exposure condition together with the mean depth of damage in millimeters. Here the phenomenon of dermal shrinking in severe burns is illustrated by the 15 cm. - 150 gm. exposure. This shrinking and loss of cellular detail appears to take place before any great degree of penetration of the fat is seen.

The lateral margins of the burns were all sharply defined as judged by staining reaction and cellular changes. No appreciable cellular damage could be associated with the surrounding flush observed on the surface.

The results of depth measurement of each burn are listed in Table III which shows the rather large spread in depth of the more severe lesions. While the use of a mean depth provides a convenient figure to work with, this spread must be kept in mind when dealing with the more severe burns.

The relationship of incident energy to depth of damage is shown graphically in Fig. 3 using cal/cm² as the ordinate and mean depth of damage in millimeters as the abscissa.

TABLE II
MICROSCOPIC EVALUATION

Tray-Skin Distance (cm.)	Magnesium Charge (gm.)	Mean Incident Energy (cal/cm ²)	Mean Depth of Damage (mm.)	CHARACTERISTICS
15	50	11.4	.73	Epidermis destroyed. Deep dermal damage with edema. Junction with normal tissue ill-defined.
	100	21.4	1.15	Full thickness dermal damage with destruction of structure and shrinking. Hair follicles in fat damaged.
	150	-	.90	Same as above with more fat damage. Dermis about 50% normal thickness.
30	50	4.8	.18	Uniform dermal-epidermal separation. Uniform superficial dermal damage with deeper damage of follicles. Junction with normal tissue not sharp.
	100	10.2	.50	Severe superficial dermal damage with structural loss. Deeper dermis retains structure. Sharp demarcation between damaged and normal tissue. Follicular damage extends into fat.
	150	13.5	.60	Dermal damage nearly full-thickness with very deep follicle damage. Dermis somewhat shrunken.
45	50	2.6	*C.E.D.	No dermal damage. Some areas of dermal epidermal separation with skip areas.
	100	5.3	.3	Dermis irregularly damaged, indistinct junction with normal. Structure preserved. Follicular damage somewhat deeper.
	150	7.6	.58	Uniform dermal damage approaching full-thickness. Edema of damaged tissue. Sharp junction with normal.

*C.E.D. - Complete Epidermal Damage

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TABLE III

RESULTS OF MICROSCOPIC EVALUATION OF DEPTH OF DAMAGE

Skin-Tray Distance in Cm.	Magnesium Charge in Grams	Depth of Damage in Millimeters																		
		P.E.D. ¹	C.E.D. ²	0- .1	.1- .2	.2- .3	.3- .4	.4- .5	.5- .6	.6- .7	.7- .8	.8- .9	.9- 1.0	1.0- 1.1	1.1- 1.2	1.2- 1.3	1.3- 1.4	1.4- 1.5	1.5- 1.6	1.6- 1.7
15	50						1		1		1					1				
	100										1			1		1				1
	150							1		1					1		1			
30	50			1	1	2														
	100					1	1	1					1							
	150							2	1				1							
45	50		4																	
	100					2	2													
	150						2		1					1						

P.E.D.¹ - Partial Epidermal DamageC.E.D.² - Complete Epidermal Damage

Figure 3

Depth of Damage vs. Incident Radiant Energy

PED - Partial Epidermal Damage
CED - Complete Epidermal Damage

DISCUSSION

Magnesium flash powder is obtained in uniform lots from a commercial manufacturer*. Shipments may vary somewhat in ignition time and radiant energy output but, in our experience, reasonable uniformity is maintained within each lot. By determining the ignition time and energy output on samples from each lot a suitable working range and charge can easily be fixed to meet the requirements of any particular experiment. The data from these experiments indicate that close range firing and, to a lesser degree, ignition of large charges increase the variance of incident energy. These larger variances are probably due to a blast of hot gas contacting the calorimeter at the 15 cm. distance, and to some loss of flame shape with the 150 gm. charge. This latter problem could probably be overcome by altering the shape of the firing tray, or by simply increasing its cross sectional area.

Spatter of burning magnesium particles to give a contact burn has always been a potential objection to the magnesium source. At the time of ignition there is a varying amount of this spatter. In a previous experiment (8) we made motion pictures of representative flashes and saw little skin-particle contact. Further, the uniform surface appearance seen in most of the burns in these experiments speaks against any contact burns.

Surface grading of burns is usually more convenient than biopsy assessment. The biopsies in this work indicate that the surface appearance accurately reflects the depth of damage up to a point, but that penetration beneath a char may proceed with little additional change in the surface criteria. At the 15 cm. distance both 100 gm. and 150 gm. charges gave identical appearing burns, yet the microscopic characteristics of these same burns

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*Kilgore, Inc., Westerville, Ohio

were quite different (Table II). We were able to enter the 5+ grade of injury with 7.6 cal/cm^2 , yet increasing the incident energy threefold could not produce a corresponding change in the surface grade. This limitation is evident in Fig. 2.

The calorimetric measurements, with their comparatively small variance, and uniformity in burns for all magnesium-distance combinations establishes this as a reliable, reproducible method for creating large area flash burns. This is the first time that such a source has been proven to be effective for this purpose.

SUMMARY AND CONCLUSIONS

1. Magnesium flash powder has been used in 50, 100 and 150 gm. charges at three distances from animals for the infliction of large area flash burns.
2. Incident radiant thermal energy has been measured in cal/cm^2 by a cone calorimeter and found to be quite consistent for each charge-distance combination.
3. Burns have been evaluated both by surface appearance and microscopic measurement of depth of damage. The microscopic pathology of the lesions is discussed.
4. By both methods of evaluation, the burns from all charge-distance combinations are surprisingly uniform. In particular, the distances of 30 and 45 cm. are most satisfactory both from the lesion produced, and uniformity of incident energy. Further, charges of 50 and 100 gm. at these two distances cover the entire range of surface grading usually employed in experimentation, while maintaining a very small variance.
5. The data indicate that magnesium flash powder makes an excellent laboratory source of radiant thermal energy for the production of large area flash burns, both from the standpoint of reproducibility of the burn lesion and of the uniformity of incident energy.

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