AN EXPERIMENTAL STUDY OF CHEMICAL BURNS

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Very little experimental work has been carried out on chemical burns, in contrast to thermal burns. Apart from experimental procedures, there are usually scant and controversial suggestions on treatment of chemical burns in most relevant text-books. The opportunity to study acid and alkali burns, therefore, was eagerly accepted when the Department of Surgery was approached by the medical officers of the Cape Division of African Explosives and Chemical Industries to carry out such investigations.

MATERIAL AND PROCEDURE

Four young pigs, each weighing approximately 50 lb., were put at our disposal. It is well known that human and pig skin are anatomically similar and, although pig skin does not blister when burnt, it can be accepted that the macroscopic and microscopic changes would closely resemble those of human skin under similar conditions.

The following is a list of acids and alkalis which are used at the explosives factory, those most commonly used being italicized. For convenience, we numbered them thus:

No.	*Acids*
1	*Oleum (fuming sulphuric acid)* — 26·5% free SO_2
2	*Concentrated nitric acid* — 97% HNO_3, 0·3% HNO_2
3	*Weak nitric acid* — 47·5% HNO_3, 0·3% HNO_2
4	Manohydrate — 99% H_2SO_4
5	Fertilizer acid — 78·5% H_2SO_4
6	*Nitroglycerine mixed acid* — 39% HNO_3, 0·3% HNO_2, 60% H_2SO_4, 0·7% H_2O
7	Collodion cotton mixed acid — 24% HNO_3, 0·3% H_2NO_2, 61% H_2SO_4, 14·7% H_2O
8	*Nitroglycerine spent acid* — 80% HNO_3, 0·5% HNO_2, 78% H_2SO_4, 13·5% H_2O
9	C.P. hydrochloric acid — 32% HCl
	Alkalis
10	50% *Caustic solution*
11	3% Caustic solution
12	10% *Alcoholic potassium hydroxide*
13	25% *Liquor ammonia*, HN_4OH
14	*Quicklime*

As 'treatment' for acid burns, the following were used in turn: running water, dry rag, a rag previously impregnated with sodium-bicarbonate powder, and these neutralizers:

1. Buffered phosphate solution, made up to the following formula: Potassium dihydrogen phosphate (KH_2PO_4), 27·22 G.; dibasic sodium phosphate (Na_2HPO_4 DH_2O), 71·63 G.; distilled water, 1 litre; and brilliant green, 0·01 G.
2. Triethanolanine.
3. 96% Alcohol plus 1% ammonia.
4. Sodium-bicarbonate powder.

For alkali burns, the following were used: running water, dry rag, and these neutralizers:

1. Buffered phosphate solution.
2. Weak solution of acetic acid.
3. 96% Alcohol plus 1% acetic acid.

Application of Chemicals to the Pigs

A square $1\frac{1}{2}'' \times 1\frac{1}{2}''$ was cut into a strip of $\frac{1}{4}$-inch-thick perspex, to ensure that the burns were of equal size. The quantity of chemical applied was accurately measured with a pipette and rapidly sprayed into the square from a distance of approximately 6 inches. The undersurface of the perspex was coated with a thick layer of 'vaseline' to prevent the adjacent area of skin from being burnt as well.

The pig's back was shaved and the animal was held by two assistants, a third applying the perspex square to the area of skin to be burnt. Each assistant was adequately protected against accidental burning. For the procedure no anaesthetic was given, and there was no evidence of pain to the pig unless 'treatment' was too long delayed. The burns were dressed with 'jelonet' and no local or parenteral antibiotics were used. The pigs were separately housed, since it was found that they tended to interfere with one another's dressings. Each pig was given a card on which the experimental procedure and progress was recorded.

For biopsies, skin grafts, and many of the photographs, the pigs were anaesthetized with intravenous 'sagatal', injected into an ear vein.

Symbols Used for Correlating Results

In correlating macroscopic results, the following system was used: − = no change, or healed; ± = superficial burn or nearly healed; and + to ++++ = degree of burn.

This system was further correlated histologically, thus: ± = superficial burn (S), i.e. epidermal basal epithelium intact; + = partial-thickness burn (P), i.e. some dermal epithelial elements still viable; and ++ to ++++ = full-thickness burn (F), to a varying degree, i.e. all epithelial dermal elements involved, although the sweat glands often looked normal.

EXPERIMENTS

Experiment 1

Comparison of treated and untreated burn (Fig. 1).

Oleum (acid no. 1) and concentrated nitric acid (no. 2) were applied as described above. No treatment was given. Anterior to these burns the acids were applied again, and washed off with plenty of water after 20 seconds. On the 9th day, on inspection and photography, the untreated burns appeared as 2 deep ulcers with central sloughs involving the whole thickness of the skin and subcutaneous tissue, with visible but unaffected muscle aponeurosis at the base of each ulcer. The water-treated burns were covered with a dry, fairly healthy-looking scab. Within 3 weeks the treated burns were healed, whereas the untreated burns took another 3 weeks to heal, leaving a puckered scar.

Fig. 1. Experimental animal on 9th day showing two untreated chemical burns posteriorly and two water-treated chemical burns anteriorly (experiment 1).

Experiment 2

Comparisons of neutralizers and water (acid no. 6 used).

This experiment was done to compare the effectiveness of the various neutralizers with that of water. The area of burn and the time interval (15 seconds) before treatment was commenced was the same for the water and each neutralizer used. The burns were inspected and biopsies taken on the 3rd day, with further recordings on the 10th and 17th days.

The results were:

Treatment	*Macroscopic findings after*			*Histology on 3rd day*
	3 days	*10 days*	*17 days*	
Impregnated rag	+	±	−	P
Sodium bicarbonate	++	++	±	F
Buffered phosphate solution ..	+	±	−	P
Alcohol + ammonia	++++	+++	+	F
Triethanolanine	++	±	−	F
Water	+	−	−	P

Experiment 3

Oleum was used in this experiment to assess the merits of dry treatment compared with wet treatment. Many factory workers believe that oleum gives a more severe burn when in contact with water, postulating that a thermal burn is superadded to the chemical burn. It has been said that the added water, as well as the water in the tissues, becomes hot. Oleum was added to various quantities of water in a test-tube, but no significant temperature rise was found.

The results of this experiment were:

Treatment	*Macroscopic findings after*			*Histology on 3rd day*
	3 days	*10 days*	*17 days*	
Impregnated rag	+	±	−	P
Wet cottonwool dressing	++	++	±	F
Triethanolanine rinsing	++	+	−	F
Water rinsing	++	+	−	F
Triethanolanine compress dressing	++	++	±	F

The time interval before treatment was begun was 15 - 20 seconds.

Experiment 4 (Fig. 2)

It was soon apparent that the time interval before treatment is commenced is most important. In previous

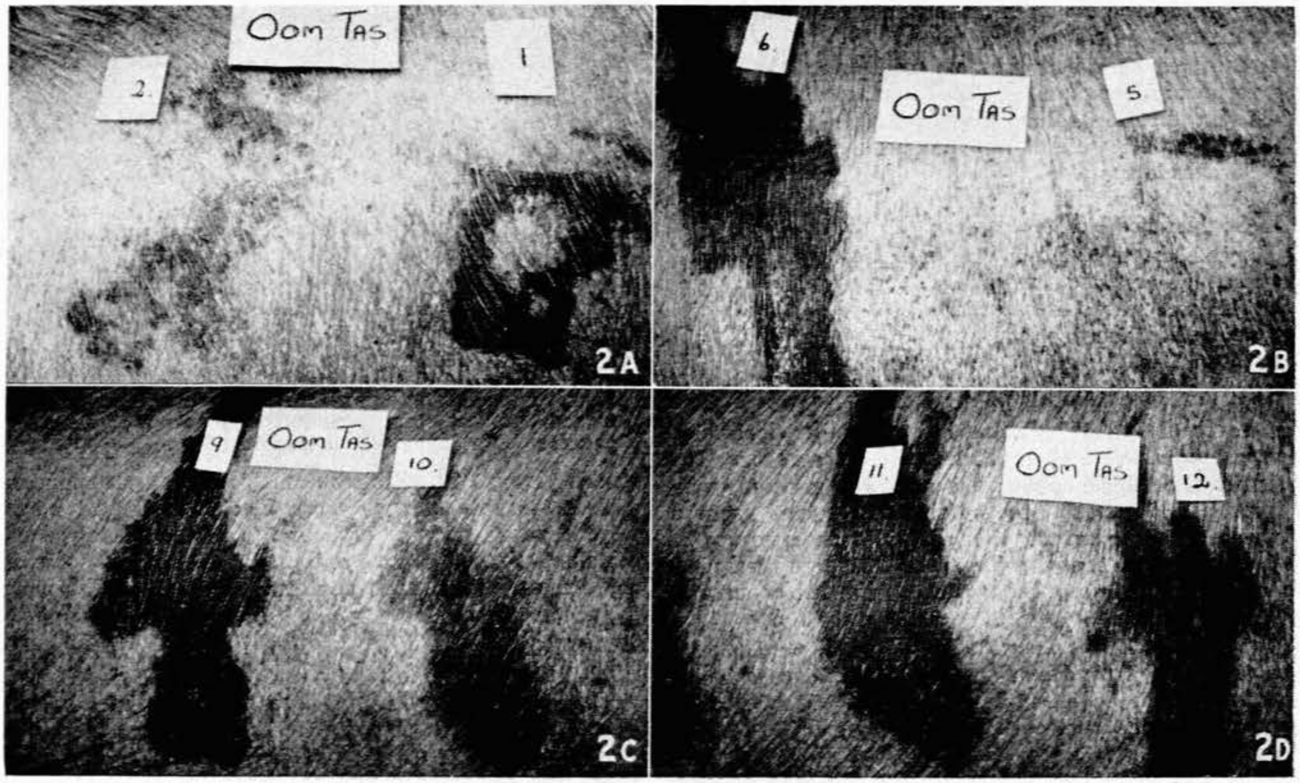

Fig. 2. Importance of time interval in treating chemical burns (experiment 4).
A. Acid burn wiped with a dry rag: (1) 5-second delay, (2) no delay. Inspection on 3rd day.
B. Acid burn treated with running water: (5) no delay, (6) 15-second delay. Inspection on 3rd day.
C. Area 9, inspected on 3rd day, shows result of 15-second delay in treating an acid burn with buffered phosphate solution (the skin had healed where there was no delay and was not photographed). Area 10, inspected on 3rd day, shows result of *rubbing* the acid off immediately and then applying water.
D. Area 11 shows result of washing the acid off with running water after a 15-second delay. Area 12 shows result of a 5-second delay before wiping acid off with a dry rag and then waiting 15 seconds before applying running water.

experiments, where there was a constant time interval of 15 seconds or more, significant burns were found. In this experiment the time interval before treatment was varied, as was the type of treatment. Acid no. 6 was used, and timing was done with a stopwatch.

The results were:

Treatment	*Delay (secs.)*	*Macroscopic findings after* 3 days	10 days	16 days	*Histology on 3rd day*
Wipe with dry rag ..	0	±	−	−	S
	5	+	+	−	P
	15	++	+	−	F
	30	+++	++	+	F
Running water.. ..	0	±	−	−	Healed
	15	++	++	+	S to P
	30	++	++	+	F
Buffered phosphate solution	0	−	−	−	Healed
	15	++	±	−	S to P
Wipe and water ..	0	±	±	—	S
Wait 5 seconds, wipe with dry rag; wait 15 seconds, then apply running water ..	5–15	++	+	−	F

Experiment 5 (Fig. 3)

In this experiment the value of grafting the delayed burn with skin was assessed. The pig was burned as usual and the areas were photographed after 3 hours. Alternate burn areas were excised and a partial-thickness skin-graft, taken from another area on the animal's back, was immediately applied. Acid no. 6 was used, with the following results:

Area	*Treatment*	*Delay (secs.)*	*Macroscopic findings* 8th day	14th day
1	Wipe with rag, then running water ..	30	++	++
2	Ditto plus graft	30	Graft taken	−
3	Wipe with rag, then running water ..	0	−	−
4	Ditto plus graft	0	Graft taken	−
5	Wipe with rag, then buffered phosphate solution	0	−	−
6	Ditto plus graft	0	Graft taken	−

Areas 2, 4 and 6 were grafted. On the 8th day, area 1 showed a significant full-thickness burn, whereas area 2 had good skin cover. In areas 3 - 6, where there was no delay, the ungrafted area had healed on the 8th day, and the grafted area had good skin cover, but was obviously unnecessarily grafted. Area 1 took almost 4 weeks to heal, with a poor cosmetic result compared with area 2.

Experiment 6

Experiment 5 was repeated, using acids nos. 1 and 2, both of which are stronger than no. 6. The results were:

Acid no.	*Area*	*Treatment*	*Delay (secs.)*	*Macroscopic findings on* 8th day	14th day	28th day
1	1	Wipe + buffered phosphate	30	+++	++	—
1	2	Wipe + buffered phosphate + graft..	30	Graft taken	—	—
2	3	Wipe + buffered phosphate	30	+++	++	+
2	4	Wipe + buffered phosphate + graft	30	Graft taken	—	—

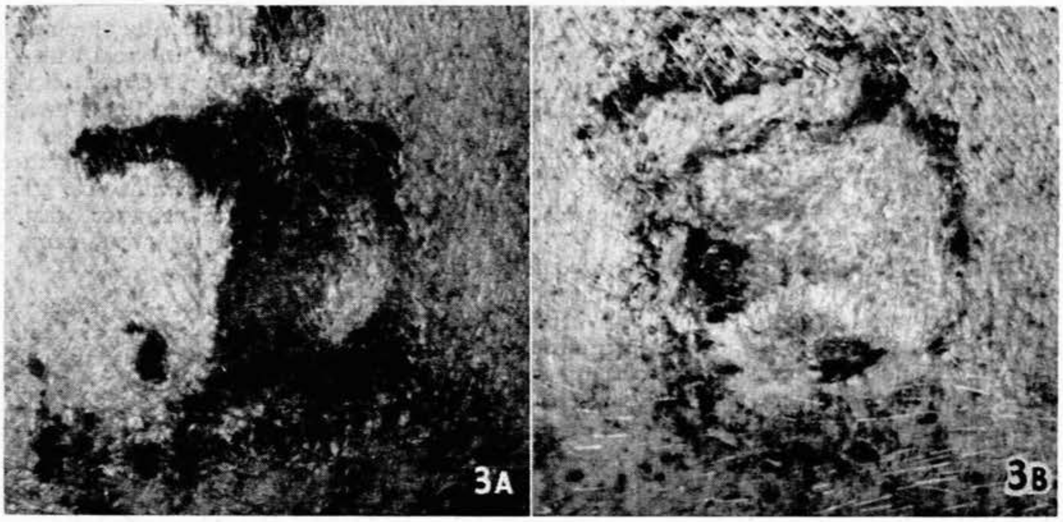

Fig. 3. Comparison of grafted and ungrafted chemical burns (experiment 5). *A*. Inspection of ungrafted area on 8th day, showing delayed healing. *B*. Inspection of grafted area on 8th day, showing a good 'take'.

Experiment 7 — Alkali Burns

Alkalis nos. 10 and 13 were used in experiments similar to those with acids described above. Each was applied and, after a 15-second delay, treatment was either: wipe with a dry rag, wash with running water, or wash with running buffered phosphate solution. On the 3rd day the areas were inspected and all were found to be healed. It is obvious that the alkalis used in this experiment do not cause significant skin burns.

CORRELATION OF HISTOLOGICAL FINDINGS

The histological findings correlated fairly closely with the macroscopic grading, with some variations. Biopsies were taken by knife on the 3rd day, since it was felt that the full effect of the burn should be obvious by then.

Changes in Superficial Burns

The basal epidermal layer was intact. Often there was 'splitting' of the stratum corneum or else this layer had disappeared. Cytoplasmic oedema with pyknosis of the nuclei was often seen. In some slides the basal nuclei were pyknotic. 'Epidermal abscess formation' was often seen, i.e. a round-cell impregnation, with a little exudate in the prickle-cell layer. In some slides, the cells superficial to the prickle-cell layer had disappeared and were replaced by an exudate of necrotic material and white-blood corpuscles.

Changes in Partial-thickness Burns

In some slides, the epidermis appeared intact, i.e. the epidermis still covered the dermis, but the cells obviously were not viable and stained poorly, often with perinuclear vacuolation, elongated and pyknotic basal nuclei, and sometimes nuclear disruption. In the dermis several changes were to be seen. Dermo-epidermal separation occurred in some biopsies, with this space infiltrated by white-blood corpuscles.

The collagen often showed 'banding', i.e. long strands running parallel and into each other. Sometimes leucocytic infiltration occurred between the bands.

The hair follicles varied in appearance from normal-looking follicles to follicles with minor changes, such as intercellular cytoplasmic oedema with poorly staining nuclei.

The sweat glands and many ducts showed no change as a result of the partial-thickness burn. The sebaceous glands showed slight changes, such as fat release by the cells. The changes in the capillaries were never significant, and occasionally intimal thickening of the vessels was seen.

Changes in Full-thickness Burns

The changes were marked in the dermis. The collagen showed the usual banding, with white-cell infiltration in some slides. The hair follicles were affected, the intercellular splitting was marked, and the constituent cells were obviously dead. The sweat-gland ducts were seen as long, homogeneous masses, with a barely discernible cellular element. Many of the sebaceous glands had released their fat, with separation of poorly staining constituent cells.

The cells of the sweat glands also showed changes, with some intercellular splitting and irregularity of the cells. Only a few slides showed actual destruction of sweat glands. The deeper dermal capillaries showed endothelial thickening and, sometimes, thrombosis.

DISCUSSION

Acid and alkali burns are normally due to the splashing of these chemicals on to the hands and/or face. Unfortunate accidents, such as falling bodily into acid or alkali or the plunging of a whole limb into either chemical, are serious. When the worker is soaked with these chemicals, valuable time is lost in removing the clothing before treatment is commenced. In these experiments, the effect of soaked clothing was not reproduced, for obvious reasons. These remarks, therefore, are applicable mainly to 'open' contact burns.

The acids and caustic alkalis are hygroscopic, i.e. they remove tissue water and, in addition, combine with protein to form a protein water.[1] The acids soften and can dissolve epithelium and, in contact with tissue water, a thermal burn (increasing the depth of the burn) is added to the main chemical action.

A point to be stressed is that a chemical burn is often insensitive to pin-prick, even in the more superficial cases, and Sevitt[1] felt that it was necessary to wait before grafting. I believe this could be refuted by some of our findings, as will be discussed.

Macroscopic Findings

All burns were inspected on the 3rd day and showed a dry scab, except in one or two cases, where they were treated either with alcohol and ammonia or the 'bicarbonate bomb', when they were moist and obviously full-thickness. Oleum produces a black eschar, in contrast to nitric acid which produces a yellow scab, and can be easily recognized. The alkalis produce an intense erythema, but with the alkalis tested there was far less skin change than with the acids.

Treatment

Evaluation of treatment was the main purpose of these experiments and some definite conclusions were reached.

In experiment 2, where nitroglycerine mixed acid (HNO_3, 39%, and H_2SO_4, 60%) was used, wiping with impregnated rag, or treating with running water or buffered phosphate, gave better results than triethanolanine, alcohol and ammonia, or the 'bicarbonate bomb'. Alcohol and ammonia were the weakest neutralizers and their value is suspect. We were unimpressed by the neutralizing powers of triethanolanine or bicarbonate powder. It must be stressed that the chemical must be wiped and not rubbed off, since it has been shown that rubbing makes the burn worse.

In experiment 3, oleum was used and the effect of water on oleum burns was assessed. In adding measured quantities of water to oleum, there was only a slight temperature rise and it could be accepted that tissue water, likewise, does not rise in temperature sufficiently to produce a more severe burn. Wiping the acid off with a dry rag gave slightly better results compared with the use of running water, but the difference was not marked.

The time relationship is very important. Immediate treatment, whether wiping, or using running water or buffered phosphate, will prevent a serious burn. Buffered phosphate is the most effective, and on the 3rd day the skin looked almost normal when it had been used, compared with some residual change in burns treated by other methods.

A delay of 5 seconds still produces a burn. Although this is only partial, it is severe enough to show a lesion on the 10th day. A delay of 15 seconds will destroy the epidermis and histological examination will show that the epidermis has separated or, if it is intact, that the cells are dead. The dermis shows definite although minimal changes. This burn heals because of intact dermal epithelial elements. A 30-second delay is most unfortunate and a full-thickness burn is inevitable. The epidermis is completely destroyed as is a significant amount of dermal epithelium. On the 16th day these burns were still unhealed.

It is obvious that the speed of first-aid treatment is very important. Before discussing this, the value of skin-grafting must be considered.

The burns produced by nitroglycerine mixed acid, oleum and concentrated nitric acid with a 30-second delay, were all grafted 3 hours after contact with these acids. On the 8th day after grafting, these areas were healed, whereas the ungrafted areas were still not healed on the 16th day. Histologically, the healed ungrafted burns showed soft, early fibrous tissue, with some granulation-tissue elements still present. I feel convinced that the neglected chemical burn, like the molten-metal burn, should be treated by primary skin-grafting.

First-aid treatment. The worker must wipe the acid off immediately with any rag available, whether impregnated or not (cotton waste, a handkerchief or shirt, or anything similar will do), and then make for running water. The initial wiping could be done *en route* to the water, and immersion must be for at least 3 minutes, preferably longer. If water or buffered phosphate are immediately available, they should be used initially, since their use prevents the rubbing in of the acid by an anxious worker.

Where there is a delay of 15 seconds — if no rag is available — then water or buffered phosphate must be found as soon as possible. Of the two, buffered phosphate will be most beneficial. In most factories, water vats and showers are placed in certain sites, and it is naturally imperative that new recruits to the factory be informed of these.

A delay of 30 seconds will cause irreversible changes, whatever first-aid treatment is used. When treatment becomes available, running buffered phosphate followed by a buffered phosphate compress is probably of some limited value; this neutralizer certainly does not enter the deeper tissues to neutralize the acid. In such cases, the medical officer should definitely consider primary skin-grafting. Experimentally, it was quite obvious how deep the burn had to be excised, and the same findings will no doubt be made on human skin.

Dressings. Where skin grafting is not contemplated, sterile vaseline-gauze is a good dressing, with the addition of polybactrin powder, if available. Buffered phosphate or triethanolanine dressings are not necessary. If the burn becomes infected, 'furacin' or eusol dressings may be used. Once a slough forms, daily dressings of half-strength eusol with sterile liquid paraffin are very satisfactory.

CONCLUSIONS AND SUMMARY

Speed is the most important factor in treating chemical burns, and fancy neutralizers should not be sought, since this search wastes valuable time. There should be no hesitation in excising the delayed burn and performing primary skin-grafting.

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1. Sevitt, S. (1957): *Burns*. London: Butterworth.