SOME MEDICAL PROBLEMS OF MUSTARD GAS POISONING.1

BY MAJOR W. R. GALWEY, O.B.E., M.C., M.B., D.P.H.

Royal Army Medical Corps (Res. of Off.)

In the European War the introduction of weapons which distributed asphyxiating, poisonous, or other gases, and analogous liquids and materials, added to the heavy responsibility which the Medical Services already carried, and presented them, and the research laboratories which served them, with new and intricate problems. In the later stages of the war the development of chemical warfare necessitated the creation of a special organization, from which the Chemical Defence Research Department has evolved. All the early anti-gas work was done under the ægis of the Army Medical Department, and much of it in this College. The names of Colonel Sir William Horrocks and Colonel P. S. Lelean stand out as those of pioneers in the organization of anti-gas research.

Before the German gas attacks in April, 1915, little was known outside the laboratory of the pathological action of many of the substances used in chemical weapons. It is therefore not remarkable that there was, at first, some confusion of thought as to the manner in which lesions were produced, and that lines of treatment should have been followed which, on a clearer understanding, were dropped.

The lack of knowledge of the action of chemical warfare materials, and the terror which they inspired, created a false impression of their deadliness, which was fostered by propaganda. However, a study of the invalidity figures of this and other countries, particularly those in the last volume of the Official Medical History of the War, makes it clear that against a disciplined force properly equipped with anti-gas appliances, and trained to use them, chemical weapons caused no more destruction than other weapons of war. Nor is there anything to show that the suffering they caused was greater than that inflicted by other weapons.

Research carried out during and since the war has enabled us to classify these poison gases according to their physiological action. The methods of studying them have been standardized, and it is now possible rapidly to assess the potency of a particular substance and the type of lesion it will produce. Incidentally, this work has given, and is giving, considerable help in the problems of protection of workers in hazardous industries.

We now divide warfare gases into three broad classes: (1) Tear gases, or lachrymators; (2) lung irritants, including the true lung irritants, e.g., chlorine and phosgene, and the irritant smokes which are mostly solid organic arsenical compounds; (3) the vesicants.

Much has been said regarding more deadly gases which may be used in future

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wars, but although over a thousand compounds have been examined in this and other countries, so far as I am aware no substance has been found which is of a wholly greater order of potency than those already used. It is, however, clear that the known warfare gases could be used more effectively than they were in the European War.

I shall chiefly consider the vesicant—mustard gas—the most potent of all the chemical weapons as a producer of casualties. However, our respirators now give complete protection against any concentration of the warfare gases likely to be met with in the field. Amongst other nations also, respirator research has developed greatly, and it is thought that most nations now have adequate protection in this respect.

Like all other chemical warfare agents, mustard gas was discovered in the course of ordinary research long before the war. Its chemical name is dichlorodiethyl sulphide. In its pure state it is a clear, colourless and somewhat oily fluid, with only a faint odour. It boils at 217° C. (412° F.), and becomes a white crystalline solid at 144° C. (58° F.). It is heavier than water, it vapourizes slowly at ordinary temperatures, and so tends to persist on the surface on which it falls.

Since pure mustard gas freezes at a relatively high temperature, it is used in chemical weapons mixed with a suitable solvent. As generally used it is a dark heavy liquid, which leaves a stain, and whose odour is more pronounced than that of the pure compound. It freezes at about 7° C. (44° F.).

Mustard gas has certain outstanding features which must be remembered:

(1) **Stability.**—It is not easily broken down into harmless compounds by substances ordinarily available in the field.

(2) **Solubility.**—Whether as vapour or as liquid, it is readily soluble in many oils, such as fuel oils and greases, animal and vegetable oils and fats, and in organic solvents, such as petrol, alcohol, chloroform, etc.

It is slightly soluble in water (under 1%), but the solution is dangerous to handle. On solution it is gradually hydrolysed to a harmless compound.

(3) **Persistence and powers of penetration.**—Like an oil it penetrates most ordinary substances, but does so more readily. Once it has penetrated, being persistent, it will give off toxic vapours for a time depending upon the prevailing weather conditions. The vapour of mustard gas readily penetrates all ordinary clothing.

(4) **Odour.**—Since at present the most sensitive means of detecting mustard gas in the field is by the human nose, it is important to be able to recognize its characteristic odour. It has been likened to mustard, to horse radish, onions and garlic. It is important to remember that, as with other odours, the sense of smell becomes quickly fatigued, so that after a time in a mustard atmosphere one fails to recognize it. On breathing pure air for a short time, as for instance by wearing a respirator, the sense of smell recovers.

(5) **Toxicity.**—Both as vapour and as liquid, mustard is exceedingly poisonous. A drop 1 mm. in diameter will produce a blister the size of a sixpence. But it is essentially a local poison, acting only on those tissues with which it comes in contact. The eyes are the organs most sensitive to mustard gas, next the lungs and respiratory passages, and last the skin.

(6) **Insidious action.**—Small drops of mustard falling on the skin do not attract attention by a sensation of cold as do more readily volatile substances, nor do they at once cause smarting or other sensations, so that contamination may be unsuspected.
Delayed action.—There is always a delay before the onset of the signs and symptoms. This period depends upon the concentration of the gas and the length of exposure. The action is cumulative, so that prolonged exposure to low concentrations may result in injury.

It is important to note that although we speak of a delayed action in mustard gas poisoning, this delay is only clinical, i.e., no gross signs or symptoms are manifest until some hours after exposure. In reality, damage to tissue begins immediately mustard gas has penetrated the cells, and as early as ten minutes after its application to the skin of a rabbit, microscopic examination gives evidence of damage in pyknotic nuclei, shrunken cells, dilated blood-vessels, and commencement of leakage from the blood-vessels.

Delayed healing.—Mustard gas penetrates the skin rapidly, and once it has penetrated deeply there is marked delay in healing of the resulting lesion. The tissues are devitalized, and as a result are readily abraded by rubbing or pressure, and form an excellent nidus in which organisms flourish. On the other hand, if the injury is only a mild inflammation or superficial blisters, the condition may clear up in a few days.

Sensitivity.—Some persons are hypersensitive to mustard gas. It is not yet certain what proportion of an average population such hypersensitives would form; it would probably be very small. Hypersensitivity can be acquired, and some research workers, after a series of mild burns incurred during experiments, have become so sensitive that if only minute traces of mustard gas are present they react fairly severely. It may be that amongst troops repeatedly exposed to mustard gas such acquired hypersensitivity would become a serious matter.

Mode of action.—In spite of prolonged and exhaustive research, we are still ignorant of the mode of action of mustard gas. We know by microscopic examination of sections of skin and other organs the sequence of events following its application, but we know little or nothing of the underlying mechanism by which these events are brought about.

Some fourteen hypotheses have been advanced to explain the action of this substance, but in every case either experimental observation has disproved it, or experimental confirmation is lacking. I shall, however, outline the more important of these to illustrate the complexity of the subject. The earliest is:

The acid hypothesis.—Mustard gas on hydrolysis breaks up into hydrochloric acid and thiodiglycol, and it is believed by the supporters of this theory, amongst whom are Marshall and his co-workers in America [1], that this liberation of acid causes the damage in the tissues.

Peters and Walker [2], however, in this country have shown that the rate of liberation of acid in a series of allied compounds does not run parallel with their vesicant action. Many substances which liberate acid are non-vesicant, and vice versa. They further point out that the cell, by means of its buffering system, is well able to cope with small quantities of acid. Application of alkalies to a mustard burn aggravates rather than alleviates it.

The sulphydryl hypothesis.—This was developed as the result of investigating the possible interference of toxic agents in oxidation-reduction processes. It postulates that irritant action is the result of destroying the sulphydryl constituent of tissue. There is no evidence that mustard gas itself affects the sulphydryl group, but mustard
Gas on oxidation forms a sulphone, and although in vivo no evidence has been obtained of the sulphone affecting the SH group, in vitro it was found that sulphone did inhibit oxidation involving this group.

The sulphone of mustard gas has been shown to be on injection more toxic than mustard gas itself. We have, however, been unable to obtain any evidence of the presence of sulphone in the tissues after the application of mustard gas.

Lewis [3] thinks that mustard gas acts by the liberation from the cells of a histamine-like body. This may be so, but it does not explain how mustard gas initiates the production of such a substance.

Stimulation of sensory nerves.—Dixon [4] claimed that mustard gas acts by stimulating sensory nerve endings, which initiates an axon reflex with resulting dilatation and leaking of capillaries. It has, however, been found that mustard gas is quite effective on denervated skin.

It will be seen from this brief summary that none of the hypotheses so far put forward has given a satisfactory explanation of the action of mustard gas, nor has it been found possible to determine whether the sulphur atom or the chlorine atom is responsible for its toxicity. The clinical picture of mustard gas poisoning is well known from official textbooks.

After this brief survey of its characteristics we will turn to the problems which will confront us should mustard gas be used in another war.

We must first consider the ways in which it was used in the last war, and compare their effectiveness with those in which it might be used in future. The only weapon used to distribute it during the war was the artillery shell. In some cases the shell was fitted with a burster just sufficient to open it and disperse the liquid, causing gross contamination of the object on which it fell—a contamination likely to persist for a considerable time. In other cases the burster was more powerful, distributing the mustard in fine drops, whereby the immediate danger from vapour was increased, and the persistence lessened. That these methods were effective, witness the number of casualties produced. It is thought, however, that under the conditions of static warfare these casualties were caused by men carrying contaminated soil on their clothing or boots into dugouts and billets, and that the mustard gas vapourizing from such contaminated clothing gassed the wearers and their companions. It is probable, too, that a large number of casualties were due rather to exposure to vapour than to contact with liquid.

But mustard gas can be so distributed as to expose troops to greater danger, either by contamination by liquid drops or by much heavier local concentrations of vapour. I refer to distribution from aircraft. Aircraft were never used for the discharge of gas bombs during the European War, but it is said that the Spaniards discharged mustard gas bombs in their war against the Riffs. Mustard gas can also be sprayed from the air in much the same way as smoke curtains are laid, or crops sprayed with insecticides; it will come down from great heights, and drops will travel in an effective form with the wind, so that troops in the open could be sprayed by an aeroplane several miles away and at a great height above them. During a retreat or in defensive operations mustard gas can be distributed by watering carts or watering cans.

Therefore in a future war, if gas is used, troops may be subjected to more severe contamination than hitherto, with consequently severer injuries necessitating more
prolonged treatment. Further, this weapon, if used from the air, may affect not only troops in the fighting line, but also those on the lines of communication and at bases; hence every man must be constantly on the look-out for contamination.

Mustard gas has great penetrant powers, whether as vapour, or as liquid; no ordinary clothing will keep it out for more than a few minutes, and if the skin is contaminated, defensive measures must be quickly taken if burns are to be prevented. If, then, troops on the march, or in attacking formations, may be sprayed with mustard gas, it appears a very difficult problem to arrange changes of clothing and decontamination in such circumstances. The Medical Services must expect to be called upon to treat large numbers of casualties, and to dispose of their contaminated garments and refit them.

Suppose, again, a gas attack is made from the air during disembarkation and concentration of a force, demands for hospital accommodation may prove far larger than those estimated for in the early stages of a campaign.

Before discussing the measures for meeting such situations, it is well to state the general position of the Medical Services as regards defence against gas.

Advice on protective measures against gas is not the function of the medical officer; this responsibility falls upon the officer commanding the formation or unit, and he will be advised either by specialist officers, or, in the case of units, by one of his own officers who has been specially trained at the Anti-Gas Wing Small Arms School. Of course, the medical officer, if commanding a unit, has the same responsibility in this respect as any other commanding officer, but the A.D.M.S. of a division, for instance, is not the responsible adviser of the G.O.C. in anti-gas measures.

We can now consider counter-measures against mustard-gas attacks.

Collective protection.—If chemical weapons are used from the air there will be need for constant vigilance so that the presence of gas may be recognized. This need emphasizes the fact that the gravity of the menace of chemical weapons is in inverse proportion to the degree of discipline and training of the troops exposed to it. The history of gas casualties in units in the war makes this abundantly clear. Unfortunately, at present we have no simple chemical means suitable for use in the field for detecting mustard gas. The International League of the Red Cross last year offered a prize for such a detector, but the competition produced nothing of value. We have therefore to rely on sight or smell to detect mustard gas. As generally used in war, it leaves a dark stain, but it is by no means certain that this will always be so. At present the nose is our most reliable detector.

Every endeavour is being made to train troops to recognize the gas. In peace training it is not possible to use so dangerous a substance; we have, therefore, sought and found a relatively harmless substance which smells somewhat like mustard gas, and this is now used for training purposes.

Once contaminated, clothing and equipment must be rapidly disposed of and cleansed, and this is one of the most serious problems. In a war of movement the difficulties of getting large stocks of clean clothing to forward areas, and of cleansing that which has been contaminated, are very great. It seems to me that if gas is used in such circumstances against front line troops it is inevitable that large numbers will suffer from burns, since it will be impossible to provide changes of clothing before the damage is done. There are, however, certain individual protective measures which we will consider later. Some special organization will be necessary.
in order to deal with contaminated clothing and equipment, and at present the authorities are considering what form it should take.

There are several ways of getting rid of mustard gas, but if contamination is heavy, all demand fairly elaborate apparatus, which would be difficult to move further forward than railhead or some similarly organized post on the lines of communication. If the contamination is from vapour only, twenty-four hours' exposure in the open air in this climate is sufficient to render clothing safe to wear. This time can probably be considerably reduced in hot countries. Boiling for half an hour will also destroy gross contamination, and this is the method of election for oilskin protective clothing. All textiles can be decontaminated by steam, but the process is elaborate, and in many cases, if the contamination is gross, it may be better to destroy the articles. For leather articles, for machinery, rifles, guns, etc., bleach is the best decontaminating agent. It can be used either as a powder, a paste, or cream with water, or as an ointment made up with petroleum jelly.

With the exception of exposure to air, all these methods demand fairly elaborate organization, and their use in forward areas is at least limited. If forward medical units receive large numbers of casualties, they will certainly have to dispose of large quantities of contaminated clothing and equipment for this purpose, and will have to be linked up with the cleansing units on the lines of communication.

Individual protection.—The respirator is a perfect protection for those parts of the body which it covers. Further, the modern respirator does not cause the discomfort and loss of efficiency of the war-time apparatus, and can be worn for hours without causing serious inconvenience. With highly trained troops, therefore, it should be possible to minimize the eye and lung casualties from mustard gas. To prevent skin burns is much more difficult. Mustard gas as liquid or vapour rapidly penetrates everything but air-proof fabric. Air-proof suits can only be worn for limited periods, even in temperate climates, and are useless in the tropics. We do employ them—ordinary naval oilskin is quite effective—for personnel engaged on special decontamination work, but only spells of work of about half an hour's duration can be undertaken without exhaustion. Several such spells can, however, be carried out in a day.

The Mark VII cape ground sheet affords good protection against penetration by mustard gas. With the shrapnel helmet, the ground sheet and the respirator, a fair amount of protection can be given. The addition of protective gloves and leggings is also contemplated.

All our efforts to find an effective and durable method of impregnating ordinary clothing to withstand mustard gas have up to date been unsuccessful. If contamination occurs it must be quickly removed, or burns of varying degree, depending upon the concentration of the poison and the length of exposure, will result. Soap and water is effective, but the scrubbing must be thorough and prolonged. A more practical preventive for front-line units is bleach ointment. This is made up with equal parts of bleaching powder and petroleum jelly. The mixing must be thorough. In temperate climates if this ointment is applied to the contaminated skin within five minutes, even very gross contamination with liquid mustard can be neutralized, and no burn will result. The ointment has not so far proved so successful in hot climates, but further experimental work is being carried out. The ointment does its work with a very short period of contact—three to five
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minutes—and we have found that even repeated applications for short periods do not cause dermatitis.

From this brief survey it will be seen that, though the danger from mustard gas is serious, particularly if used from air weapons, much can be done to lessen it, particularly with highly-trained troops who have been taught to recognize the poison.

The problem of mustard gas is similar to that of malaria prevention, as we met it in the eastern theatres of war. Casualties are inevitable, and there is no panacea for prevention, but intelligent application of known preventive measures, with strict training and discipline, will minimize them.

REFERENCES.