THE EFFECT OF WAR GASES AND OTHER CHEMICALS ON THE EYES OF THE CIVILIAN POPULATION*

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BECAUSE in total warfare many chemicals other than war gases may injure the eyes of the civilian population these as well as war gases will be considered in this paper. However special emphasis will be placed on the diagnosis and treatment of eye injuries by war gases.

WAR GASES

The first record of the use of noxious gases is by the Spartans against the Athenians in 431-404 B. C.[1] Gas was first used by the Germans in April, 1915, in a surprise attack against the Allies in Flanders. The casualties were high because the troops had no protection. Since gas was found to be an efficacious military weapon its use became widespread during World War I but fortunately efficient protection was rapidly developed. More recently gas was reportedly used by the Japanese against the Chinese and by the Italians in Ethiopia when mustard gas oil was sprayed from airplanes. It is possible that the horrors of gas warfare will be brought to the general population at some time in the future even though there is a question of how efficacious such use of gas may be in winning a war.

Although we have little information concerning the effect of war gases on the civilian population, we do know much concerning the effect of these gases on the eyes (1) from experience in the last war, (2) from accidents in factories manufacturing war gases and (3) from experiments with animals. These three sources of information have been

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TABLE I

CHART SHOWING NUMBER AND PERCENTAGES OF CASES OF BLINDNESS IN WORLD WAR I FROM GAS AND NON-GAS WEAPONS (GILCHRIST[2])

Nature of Injury	*Cause*	*Number*	*Per Cent*
Loss of right eye	Gas	16	1.9
	Non-gas	307	37.8
Loss of left eye	Gas	10	1.2
	Non-gas	289	35.6
Loss of both eyes	Gas	4	.5
	Non-gas	44	5.3
Loss of one eye (unknown)	Gas	3	.4
	Non-gas	59	7.3
Traumatism	Gas	0	.0
	Non-gas	80	10.0
Total	Gas	33	4.0
	Non-gas	779	96.0

used in preparing this outline of injuries of the eyes which might be expected if gas warfare is brought to the civilian population.

On the whole, war gases have not proved to be very harmful to vision in a permanent way. In World War I of 812 blind or partially blind soldiers, 4 per cent of the injuries were the result of gas weapons while 96 per cent resulted from non-gas weapons. Gilchrist[2] has tabulated these cases in Table I.

Derby's[3] experience in World War I showed that from 75 to 80 per cent of the eyes affected by gas were only mild cases. Parlange[4] reported the following incidence of eye affections: three corneal ulcerations in 1500 gassed individuals; two corneal opacities in 1800 gassed individuals and 700 conjunctivitides in 4000 gassed individuals.

For practical purposes all known gases may be divided according to their actions into five groups: (1) vesicant, (2) lung irritating, (3) sternutatory, (4) lacrimatory and (5) toxic gases.

Many known war gases are capable of causing irritation, and direct or indirect injury to the eyes but practically mustard gas and lewisite are the only important ones from the standpoint of direct eye injuries. Individuals with previous eye lesions, e. g., trachoma, keratitis or old

corneal scars, suffer more acutely from contact with gas than do persons with normal eyes.[4] It is sometimes difficult to be sure to which gas a person has been exposed and shells combining mustard, phosgene and tear gas were used in World War I.[5] Another method of using gas at the time of the last war was to release shells containing sternutatory gases which would force the soldiers to remove their masks and then to release lung irritating gases. At that time the respirators afforded no protection against sternutatory gases, but present masks do since a paper filter was inserted.

Vesicant Gases

Mustard Gas: In the first World War mustard gas was used in shells and in the Ethiopian war as a spray from airplanes. Probably an attack on the civilian population would be in the latter form.

Mustard gas is also known as yperite (French) or yellow cross (German). It is known as mustard gas because of its odor and as yperite because the Germans first used it at Ypres in July, 1917. The term yellow cross is derived from the symbol used by the Germans to designate the shells containing this gas.

Mustard gas is a dark brown liquid (dichlorethylsulphide, $[(C_2H_4Cl)_2S]$, with a high boiling point (214 degrees F.) and changes slowly into a colorless gas. This gas is one of the most difficult with which to cope because earth on which the oil has fallen remains permeated for from three days to a week. The length of time depends upon the weather. Rain neutralizes the soil within three days and dry weather permits the gas to remain potent for at least a week.

Eye casualties can occur (1) as a result of direct splashing of the oil into the eyes, (2) by direct transfer from the hands to the eyes after contact with the earth, clothing or other objects and (3) by vapors. The latter is by far the most frequent.

The ocular symptoms following contact with the *vapors of mustard gas* occur only after four to six hours. Although the symptoms are severe there are no serious or permanent ocular lesions in the usual conditions of warfare, but if the eye is exposed to high concentrations the cornea can be severely damaged as experimental work has shown.

Hyperemia of the conjunctiva accompanied by tearing, photophobia and blepharospasm, appears approximately four to six hours after contact. The pain becomes very severe about eight hours after exposure to the

gas and edema of the eyelids develops. The appearance is similar to that of infectious conjunctivitis. The eyelids are swollen and in attempting to separate them with the aid of a retractor, a cloudy fluid is expressed. The conjunctiva is red with marked chemosis. In severe cases, the lower fornix is red but the part of the conjunctiva exposed between the eyelids can be porcelain white. Corneal lesions are usually discrete, but epithelial desquamation may often be revealed by fluorescein. The exposed part of the eyes between the eyelids is most affected by the vapors.

If proper treatment is administered, and frequently without treatment, edema of the eyelids disappears in a few days. Hyperemia, photophobia and tearing still persist for a week or two. Blepharospasm and photophobia may be present even longer in severe cases.

When there is *direct contact with the mustard oil* the ocular lesions are much more severe with corneal ulcers and sometimes even with perforations of the cornea. The skin and eyelids may present first degree or even second degree burns.

Late Conjunctival Complications: The conjunctiva may remain very sensitive to all irritants (wind, dust, light, etc.) and attacks of blepharoconjunctivitis often occur. In exceptional cases epiphora caused by cicatricial obliteration of the lacrimal puncta has been noted. Symblepharon may develop in some cases. There may be abnormal vascularization characterized by the persistence of conjunctival vessels of carmine color. Biomicroscopically, true varices of the conjunctiva may be seen near the limbus years later.[6]

Late Corneal Complications: The cornea in most cases returns to normal. In others leukomas develop and recurrent ulcers of the cornea have been observed after several years.[7] These serious and lasting corneal lesions may be seen especially if direct contact with the mustard oil (splash) has occurred or transfer by the fingers has been possible, but are rare if there has only been contact with the vapors of the gas.

Intra-ocular Complications: In severe mustard gas burns of the body, Beauvieux[8] and Genet and Delord[6] noted dilatation of the retinal veins and hyperemia of the disk. In his experimental work on monkeys Wessely[9] also noted some retinal hemorrhages and he believed that they were due not to the general intoxication, but to the local penetration through the burned ocular tissues; such hemorrhages occurred only in those animals which had not had a protective ointment introduced in

their eyes prior to the instillation of mustard gas oil.

Prognosis: Generally the prognosis in cases of mustard gas burns is benign. Beauvieux[8] observed only two cases in 1,800 mustard gas casualties in which severe corneal ulceration developed and even these regained useful vision.

Tissue which previously has been affected by mustard gas is susceptible to smaller concentrations of the vapor.[10]

Treatment of Mustard Gas Burns of the Eye: Although eyes that have been exposed to the vapors of mustard gas may at first look severely damaged, the prognosis is good and most cases will recover entirely even if no treatment is applied to the eyes. Especial care should be taken to avoid secondary infection and it is, therefore, better to apply no treatment at all if sterile solutions and drops are not available.

But if the eyes have been splashed by mustard gas oil, it is important to irrigate the eyes as soon as possible. The immediate and copious use of water, advised by Pellathy,[11] to lessen the action of mustard gas on the eyes because of the difficulty in obtaining proper solutions quickly, may well be the most important first aid treatment, and should be used as early as possible, preferably within fifteen minutes since most of the mustard gas has been absorbed by that time.

The patient should be assured that sight will be restored and if possible the eyelids should be separated permitting him to see. Pontocaine (½ per cent) should be instilled once or possibly twice if it is necessary to relieve pain or to temporarily separate the eyelids, but cocaine and atropine should be avoided. Ointments should not be used in the treatment of mustard gas injuries for the first few days until the chemical has been completely eliminated from the tissues since mustard gas is absorbed by any fatty substance and it is thus kept in contact with the eye. No dressing should be applied.

The eyes may be washed with alkaline solution (sodium bicarbonate 2 to 5 per cent) or neutralizing solution (dichloramine-T). Dichloramine-T may be used in 0.5 per cent solution.[12] It must be dissolved in an organic solvent (chlorinated paraffin or chlorinated diphenylether), and a local anesthetic should be instilled prior to irrigation. Hypertonic solutions* have been recommended because it is claimed they induce drainage by osmosis, thus hastening elimination of the gas.[13] Livingston

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* Saturated aqueous solution of sodium sulphate 800 grams; Simple syrup 200 grams *or* Magnesium sulphate 40 grams; Simple syrup 50 grams; Water 150 grams

and Walker[14] reported that saturation of the system with ascorbic acid, given intravenously in four rabbits, proved to have a remarkable effect in preventing the spread of keratitis and the progress of the eyelid inflammation resulting from mustard gas. However, Mann and Pullinger[15] stated that intravenous injections of ascorbic acid neither prevent nor influence mustard gas lesions of the eyelids, conjunctiva or cornea. Pickard[16] advised the external application of mercurial salve to the eyelids in order to prevent chalazia, hordeola, and small multiple abscesses of the eyelids. However, it seems better to use no antiseptics since all are irritating to the tissues and since, notwithstanding the appearance, there is no infection if the eye is properly treated.

During convalescence zinc or boric acid solution may be instilled. Tinted lenses may also be prescribed.

Experiments with Mustard Gas on Animals: Our experiments with rabbits*† have demonstrated that the ocular lesions are extremely severe if even the smallest amount of liquid mustard gas is applied to the cornea, and the tissues seldom heal with little scarring as reported by other workers, even if immediate or subsequent treatment is administered. The use of a 5 per cent sulfanilamide-sulfadiazine ointment (equal parts) applied three days after instilling liquid mustard gas does not retard healing and may tend to prevent or control secondary infection. However, we have not used dichloramine-T which Heinsius[17] claims will prevent damage if the eye is flushed within the first fifteen minutes after mustard gas is applied.

Lewisite: Lewisite (Cl CH:CHAsCl_2) was prepared for use in the last war but was never liberated. It is a heavy, oily liquid, colorless in its pure state but dark upon standing. From experimental studies, its action is similar to that of mustard gas but more destructive. According to Hughes[18] the onset of symptoms following contact either with the vapor of lewisite or the liquid is almost immediate. His experiments with rabbits showed that within an hour there is marked edema of the conjunctiva and a definite clouding of the cornea. After a few hours, necrosis of the conjunctival vessels with the formation of hemorrhagic area is quite striking and a marked fibrinous iritis develops. Hughes states that in general the subsequent course of the lewisite lesions shows more corneal edema, more intense vascularization of the cornea and

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† Mustard gas furnished through the courtesy of Dr. Kenneth C. Blanchard, Department of Biology, New York University.

more tendency to purulent exudation and corneal ulceration than is the case of mustard gas burns.

Treatment: The treatment is probably the same as for injuries caused by mustard gas but we have had no experience with it. The use of copious irrigations with water or a 1.5 per cent solution of sodium bicarbonate is recommended. Hughes[18] states that except for the use of chlorinated solutions, the treatment of lewisite burns is essentially that of mustard gas. Hydrogen peroxide and potassium permanganate for the treatment of lewisite burns have been discarded generally.

Lung Irritating Gases

Although the lung irritating gases are the most serious because of their lethal action, they are not so important from the standpoint of the ophthalmologist. However, these gases, which include chlorine, chloropicrin (CCl_3NO_2), and phosgene ($COCl_2$), are irritating to the eyes. Phosgene may be associated with intra-ocular hemorrhages which probably are secondary to the anoxemia resulting from pulmonary edema.[5]

Sternutatory (Sneezing) Gases

The sternutatory gases are in reality solids of the arsine chemical group and include diphenylarsine [$(C_6H_5)_2As$], diphenylamine-chlorarsine (Adamsite), diphenylchlorarsine [$(C_6H_5)_2AsCl$], and diphenylcyanarsine [$(C_6H_5)_2AsCN$]. These chemical substances cause irritation of the eyes with excessive lacrimation. Sneezing is the essential symptom, but nausea and vomiting as well as severe headaches also occur.

The eye symptoms are usually of short duration and after a few minutes the effects have passed.

Lacrimatory Gases

Lacrimatory gases include chloracetophenone* ($C_6H_5COCH_2Cl$) (a white crystalline solid), benzyl bromide ($C_6H_5.CH_2Br$)†, chloro-acetone ($CH_3.COC_6H_4Cl$)† and bromacetone ($Br.CH_2CO.CH_3$)†. The ocular symptoms resulting from the use of lacrimatory gases are: burning pain, excessive lacrimation, injection of the conjunctiva and photophobia and in rare cases, when the gas is splashed into the eyes, free exfoliation of the epithelial covering of the cornea. Itching, burning,

* Common tear gas used in police work.

† These last three chemicals are in liquid form.

tearing, blepharospasm and photophobia are so intense that those affected are incapable of finding their way without aid. The bulbar and palpebral conjunctivas are markedly hyperemic but there is no ciliary injection. These symptoms appear immediately after exposure to the gas and disappear within a few minutes or hours, leaving no trace except when splashed into the eyes; then the burn is similar to that produced by strong acids.

Prognosis: So far as the eye is concerned, lesions produced by lacrimatory gases are benign unless the liquid is splashed into the eye. Schmidt[19] reported a case in which tear gas (brommethylethyl ketone), which is generally considered harmless and to cause only transient irritation, was shot into an eye and produced severe destruction and permanent damage deep in the orbital tissues.

Treatment of Injuries Caused by Lung Irritating, Sternutatory and Lacrimatory Gases

The patient should be removed from the contaminated area. Even if nothing is done all eye symptoms usually disappear rapidly. Therefore, useless treatments which may cause infection if nonsterile solutions are used should be avoided. If warm sterile solutions are available the eyes should be flushed, e.g., with sodium chloride 1.4 per cent, sodium bicarbonate 2 to 5 per cent or boric acid 2 per cent. Sodium sulfite has been recommended by McNally*[5] to neutralize and dissolve lacrimatory gases. If pain is severe a sterile solution of pontocaine (½ per cent) may be instilled once or twice; if irritation persists light liquid petrolatum may be instilled.

If liquid was splashed into the eye immediate irrigation is necessary. Water should be used if no other sterile or nonirritating solution is available.

Systemic Toxic Gases

The systemic toxic gases include hydrocyanic acid, cyanogen chloride and cyanogen bromide. These gases are usually fatal in a few seconds or at most minutes. However, there are rare examples of blurring of vision and irritation of the eyes in exceptional cases surviving such an attack.

* Sodium sulfite 0.4 gm.
Water 25.0 cc.
Glycerin 75.0 cc.

Carbon monoxide is not used in chemical warfare but great quantities of it are produced when a shell explodes or when a machine gun or a cannon is fired. Intoxication can, therefore, be observed in badly ventilated dugouts or pill boxes.

Other Chemicals that May Affect the Eyes as a Result of Total War

In addition to the gases from bombs or those that may be sprayed, civilians and workers may be exposed to a great number of chemicals. If bombs fall in the kitchen or in the shop, these chemicals may easily affect the victims' eyes. These substances which are the same as those encountered in industrial casualties may cause severe eye injury.

For example, caustic soda and caustic potash lyes as well as other alkalies produce lesions of the conjunctiva and cornea. Metal workers, rubber workers and chemical workers are especially exposed to these agents. Acrolein and ammonia used in refrigerating plants and in refrigerators are important because of the severity of the eye injury when there is direct contact, e.g., necrosis of the cornea. Battery acid is another hazard which might have to be considered in addition to sulphuric, nitric and other acids which cause severe burns of the conjunctiva, cornea and eyelids.

Acid Burns: Acid burns may cause immediate injury to the conjunctiva and cornea. The prognosis depends upon the amount and concentration of acid contacting the eye, and how long it acted.

Alkali Burns: Alkali burns may cause progressive injury of the eye. Strong solutions penetrate the cornea in a few minutes causing desquamation. Dense opacities follow with pannus. Penetrating ulcer of the cornea may be a sequela.

Immediate First-Aid Treatment of All Chemical Burns: The conjunctiva is flushed. The urgency of immediate treatment does not permit a special solution being made up. Therefore, the eyes should be flushed with water and a sterile nonirritating oil (liquid petrolatum) instilled, if available. The patient should then be referred to a specialist for appropriate treatment, for example, atropine for iritis, cauterization for corneal ulcers.

Special Treatment of Acid Burns: A solution of sodium bicarbonate (2 per cent) effectively neutralizes corrosive acids. Subsequent treatment depends upon the individual symptoms encountered. The follow-

ing have been recommended: boric acid ointment and an eye pad, liquid paraffin, cod liver oil, and mild silver protein (10 per cent) followed by a 2 per cent solution of boric acid.

Special Treatment of Alkali Burns: Treatment includes flushing the eye with water, saline solution (1.4 per cent) or boric acid (2 per cent). The instillation of an isotonic acetate buffer solution* neutralizes any excess alkali.[5] Further treatment may include: atropine sulfate, 1 per cent solution, three times a day to control secondary iritis and breaking adhesions between the eyelids and eyeball by means of a glass or plastic spatula and boric acid ointment passed into the upper and lower conjunctival culs-de-sac twice a day. Secondary infection may be prevented or combatted by the instillation of a mild silver protein (10 per cent) followed by irrigation with saline solution (1.4 per cent) or the application of sulfadiazine ointment (3.5 per cent).† The immediate application of rabbit peritoneum has been recommended by Brown[20] as a protective membrane to separate the cornea from the burned palpebral conjunctiva following most corrosive chemical burns.

At a later date, the excision of superficial corneal scars or keratoplasty may be required to restore vision when the corneal scars obstruct the pupil. If adhesions form between the conjunctiva and the eyeball (symblepharon) conjunctivoplasty may be indicated. If secondary glaucoma develops it is difficult to control and may require the injection of alcohol into the ciliary ganglion. If useful vision may be restored 1 cc. of 40 per cent alcohol may be injected into the ganglion after 1 cc. of novocain (2 per cent solution) has been injected and the needle left in place. If vision is destroyed, 80 per cent alcohol (1 cc.) may be injected.

Lime burns should receive continued treatment until all danger of cicatricial contraction of the conjunctiva and secondary opacification of the cornea is past. This type of injury tends to involve the deeper layers of the cornea and sclera, even when the eye appears to be only slightly affected, causing an associated iritis.

Complications of Burns Caused by Acids and Alkalies

Complications which must be looked for and if possible prevented

* Acetic acid 2.5 gm.
Sodium acetate 3.0 gm.
Sodium chloride 4.5 gm.
Distilled water 1000.0 cc.

† Sodium sulfadiazine in aquaphor 3.5 per cent

are: corneal ulcers, iritis, glaucoma and adhesions between the conjunctiva and the eyeball.

Summary and Conclusions

Although vesicant, lung irritating, sternutatory and lacrimatory gases are expected to cause casualties, physicians must be prepared for new unknown gases. For example, arsenated hydrogen, a hemolytic gas, was considered a possibility in the fall of 1939.

Physicians are urged to remember that applying no local eye treatment will usually do less harm than using medication which may damage the eyes or solutions or instruments that are not sterile, as secondary infection is the principal danger from the external application of the war gases.

The immediate treatment of all gas and chemical injuries of the eyes is to flush the conjunctival culs-de-sac with water or a sterile solution of salt (1.4 per cent). If acid is known to have caused the burn, sodium bicarbonate (2 per cent solution) should be used. If an alkali, the conjunctival culs-de-sac should be flushed with boric acid (2 per cent solution). The immediate instillation of light liquid petrolatum is useful and contraindicated only in mustard burns. Severe pain may be controlled by instilling pontocaine (0.5 per cent solution) or butyn (1 per cent solution) once or twice but it is preferable to control pain with internal medication (morphine, allonal, etc.) as most local anesthetics have a deleterious effect on the corneal epithelium. Secondary infection should be combatted with mild silver protein or sulfadiazine solution or ointment (3.5 per cent). Iritis should be suspected in all severe burns and treated with atropine solution or ointment unless secondary glaucoma develops. Ulcers of the cornea and the secondary corneal scarring also symblepharon may require surgical treatment.

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