SIDEROSIS BULBI*

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SIDEROSIS bulbi is a pigmentary and degenerative change in the eye that follows the intra-ocular retention of a foreign body containing iron. The pathological anatomy of siderosis was first reported by von Hippel (1894), who distinguished two types of siderosis: haematogenous, in which the iron was derived from the blood, and exogenous, in which it came from an intra-ocular foreign body.

This paper will deal with the latter, discussing corrosion of iron, its diffusion and precipitation throughout the eye, the pathological changes, and the clinical picture.

Corrosion of Iron.—Corrosion is the destruction of a metal resulting from its contact with a liquid. Factors which increase the velocity of corrosion are the presence of oxidizing agents, uneven surfaces of the metal, agitation of the liquid, higher temperature, and greater alkalinity. The human eye offers an optimal situation for corrosion.

Diffusion and Precipitation of Iron.—The chemical processes in ocular siderosis have been debated for years. Von Graefe (1860) thought that the iron diffuses through the eye in the form of oxides. Leber (1882) felt that a solution of iron bicarbonate is formed, which then is oxidized and precipitated in the ocular tissues. The theory of Mayou (1925, 1926) was that iron is in the form of colloidal ferric hydroxide, which is positively charged. Bunge (1891) considered that the iron is dissolved by carbonic acid, circulated as a soluble carbonate being deposited in an insoluble form by the action of acid salts. Friedenwald (1954) believes that the staining of tissues by iron is due to ferric ions in low concentration which combine with sulph-hydryl groups in the cells.

Particles of oxidized iron tend to precipitate in ectodermal cells. Many theories have been advanced to explain this fact. Mayou (1925, 1926) feels that the activity of epithelial cells renders them negatively charged. The negative charge attracts the positively charged colloidal particles. Wolff (1951) did not ascribe to certain tissues a special affinity for iron, but thought that all living cells took up iron more readily than the connective tissue, and that connective tissue took up more iron than the glass-like membranes.

Pathology.—The epithelium of the ciliary body is the first tissue affected and the non-pigmented epithelium stains earlier. The iris is affected most at the anterior limiting layer and in the sphincter and dilator muscles. Macro-

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phages laden with iron pigment are commonly found in the trabecular meshwork. The retinal pigment epithelium is invariably affected. The ganglion cells are involved and macrophages laden with pigment surround the retinal vessels. When the lens has been damaged the subcapsular epithelium is affected.

The action of the pigment on the cells is at first irritative and later des-

tructive. The ganglion cells of the retina degenerate and are replaced by glial tissue. The cells of the retinal pigment epithelium take up iron, proliferate, invade the retina, and tend to collect around the retinal vessels.

A microscopic picture resembling retinitis pigmentosa occurs, and degeneration of the eye continues until phthisis results (Fig. 1*a-e*).

Fig. 1(*a*).—Iron deposits in dilator muscle and proliferating subcapsular epithelium of the lens.

Fig. 1(*b*).—Iron in subcapsular epithelium extending just posterior to equator.

Fig. 1(*c*).—Iron in corneal stroma, spreading from foreign body tract.

Fig. 1 (d).—Perivascular collections of iron in retina.

Fig. 1 (e).—Positive staining for iron in the trabecular meshwork and in ciliary muscle.

Clinical Findings.—The process of siderosis bulbi may be divided into three stages:

(i) Latent period following injury before clinical signs are manifest. This period varies from a few weeks to many years, depending on the site and the nature of the foreign body.

(ii) Spread of iron through the ocular tissues. The diffusing iron stains all epithelial structures with which it comes in contact.

(iii) Degeneration of the tissues, particularly the retina, due to the toxic effect of the iron.

The dilated pupil, which is one of the earliest signs of siderosis, is due to the precipitation of iron in the sphincter and the dilator muscles, rendering them inactive. Night blindness is an early symptom, probably due to the deposition of iron in the pigment epithelium of the retina. Heterochromia develops as more and more iron is deposited in the iris musculature and epithelium. Cataract and pigmentation of the lens epithelium develop if the lens capsule is injured. Iridocyclitis is a constant feature of siderosis, but

posterior uveitis does not occur unless Bruch's membrane has been penetrated. Glaucoma is a common complication and may be due either to blocking of the trabecular meshwork with macrophages or to the production of a more albuminous aqueous by the ciliary body. Loss of vision is usually due to retinal degeneration.

Cases in which the signs and symptoms of siderosis disappeared following removal of the foreign body are on record. Genet (1924) reported a case in which he removed the foreign body 7 months after the injury and the siderosis completely disappeared. Collins (1894) described an eye which returned to its normal appearance after removal of the steel.

Present Study

Material.—The clinical history and microscopic sections of twenty enucleated siderotic eyes were studied. All were from male patients ranging in age from 18 to 58 years. The most frequent source of the foreign body was shrapnel, the next being hammer and chisel. The length of time the foreign body had remained in the eye varied from one week to 13 years. The commonest location of the foreign body was free in the vitreous. At the time of enucleation vision was minimal or absent, and iridocyclitis was present in every case. In all cases in which pupillary reactions were recorded they were sluggish or absent. Heterochromia was recorded as present in seven eyes. Ocular tension was recorded as above normal in three eyes and as subnormal in three eyes.

Method.—Each enucleated eye was placed in 10 per cent. formalin for 48 hrs. and then washed in tap water for 6 hrs. The specimen was then examined grossly, and sectioned in a horizontal plane, special attention being directed to the presence and location of any magnetic foreign body. The central portion was embedded in celloidin. Sections 20 microns thick were cut and the following six staining combinations employed:

- (1) Haematoxylin and eosin.
- (2) Prussian blue.
- (3) Haematoxylin, eosin, and prussian blue.
- (4) Bleached section.
- (5) Bleached section and prussian blue.
- (6) Bleached section, haematoxylin, eosin, and prussian blue.

The sections were bleached in 0.05 per cent. potassium permanganate followed by 0.33 per cent. oxalic acid. The normal ocular pigment was bleached but the iron was not. For control purposes, eyes with a history of chronic recurrent intra-ocular haemorrhage, massive haemorrhages in the vitreous, and blood staining of the cornea were stained by these methods. The dark blue granular staining of exogenous siderotic pigment was not obtained.

Microscopic Findings.—The non-pigmented ciliary epithelium and the pars plana ciliaris were the most common sites of impregnation by iron. The prussian blue reaction was obtained at these sites in all twenty eyes. The retinal pigment epi-

thelium was the next most common site, being involved in seventeen of the twenty eyes. The iris was commonly involved, the dilator muscle showing iron in ten eyes and the sphincter in eleven eyes. The retinal ganglion cells contained iron in thirteen eyes, the internuclear layers in thirteen. Perivascular collections were present in seven. The trabecular meshwork contained iron in ten. The subcapsular epithelium of the lens was involved in seven, in each of these a rupture of the lens capsule was identified. The corneal stroma or the endothelium stained in five. The circular fibres of the ciliary muscle were affected in two. The optic nerve showed positive staining for iron in two; the choroid of two eyes and the sclera of one carried iron. In no case did the conjunctiva contain iron (Fig. 2).

Fig. 2.—Frequency of sites of positive staining in twenty cases of siderosis.

Foreign Bodies

In a survey of one hundred intra-ocular foreign bodies of a ferrous nature, all were found to be magnetic and corrosive. Hammering steel was the commonest cause of injury. A cold chisel or punch (shock tools hardened for cutting) were the commonest tools responsible. Automobile parts, such as axle bearings and king pins, were second, and nails, structural steel, and hammers were involved in that order. Broken drills, lathes, shapers, grinding, and sanding were responsible in a smaller number of cases. Explosions, dropped castings, and chains were only occasionally the cause (Fig. 3).

Fig. 3.—Origin of foreign bodies in a hundred cases. The hammer being the most likely source in 72 cases.

An investigation into the types of steel and steel alloys used in industry

and in the manufacture of tools revealed four classes of steel:

(1) *Standard Alloy*.—These contain iron, carbon, and manganese, and smaller amounts of nickel, chromium, and molybdenum. These steels are all magnetic and corrodible in dilute saline solutions. They are widely used for the manufacture of machinery and automotive parts.

(2) *Stainless*.—There are two broad classes, one magnetic and the other non-magnetic or nearly so. The non-magnetic is more resistant to corrosion than the magnetic. Chromium imparts resistance to oxidizing effects in steel, probably because of the formation of an oxide film. The natural effect of nickel is to supplement chromium, increasing the steel's resistance to corrosion. Magnetic stainless steel contains from 11 to 16 per cent. chromium. Non-magnetic stainless steel contains an additional 8 to 18 per cent. nickel. The stainless steels are widely used in the dairy, meat-packing, canning, beverage, and pharmaceutical industries, and modern hospital equipment is largely made of stainless steel.

(3) *Tool*.—There are many varieties, each developed for a specific task. There is water-hardened tool steel for maximum wear resistance in cutting tools, drills, taps, and reamers. Oil-hardened tool steel is used for tools of intricate design. High-speed hot-work tool steel is used for cutting tools, dies, and shock tools. All are magnetic and corrosive.

(4) *Manganese*.—Steel containing 12 per cent. manganese is non-magnetic and offers little resistance to corrosion. This steel is widely used for parts required to resist abrasion, such as steam-shovel bucket teeth, and the jaws of crushers and grinders.

Discussion

The incidence of siderosis bulbi is fortunately low. The majority of cases included in this study were due to war injury, sustained in situations which lent themselves to unsuspected and thus undetected, intra-ocular foreign bodies. Moreover, fragments from war missiles are commonly non-magnetic. In peacetime most intra-ocular foreign bodies are recognized early and steps for their removal are not delayed.

When a metallic foreign body enters the eye the rate of development and the severity of the resulting siderosis depend upon:

- (a) The shape, size, and corrosive properties of the foreign body;
- (b) The site of the foreign body;
- (c) The associated trauma and resulting tissue reaction.

The shape of the foreign body is important. An irregular, roughened fragment will corrode more quickly than one that is smooth and regular. The size is important from the standpoint of the area of surface available for oxidation. Small pieces may completely oxidize and the siderosis regress. The corrosive properties of the metal are important. Iron and carbon steel offer less resistance to corrosion than do some of the alloyed steels. Non-magnetic steel only very rarely causes siderosis bulbi. There are two reasons for this: its toughness greatly reduces the possibility of fragments being struck from it, and it resists corrosion even more than do the magnetic stainless steels.

The site of the foreign body governs both the rate and the extent of tissue staining. The process is rapid when the metal is bathed in the ocular fluids and slow when it lies in tissues of low metabolism such as the lens and the cornea.

Associated trauma, such as rupture of the lens capsule and Bruch's membrane, facilitates the dispersion of iron. Fibrous tissue may so completely encase the foreign body that indirect siderosis does not occur.

In many cases clinical manifestations of siderosis are complicated by traumatic disruption of the ocular tissues. However, it is safe to assume that the pupillary changes and night blindness are two direct results of the deposition of iron in the cells. The incidence and the course of glaucoma is complicated by the associated trauma and no conclusions could be drawn from this study.

In the microscopic study of siderosis, a bleached section stained only with prussian blue is ideal for the quick detection of iron. Bleached sections, stained with prussian blue and counter-stained with haematoxylin and eosin, are best for detailed study.

Summary

(1) Siderosis bulbi denotes pigmentary and degenerative changes in the eye following the retention of an intra-ocular foreign body of ferrous nature.

(2) The products of corrosion, in the form of a colloidal suspension of ferric hydroxide, diffuse slowly through the tissues of the eye, and accumulate in the more active cells of the ocular tissue, but are stopped by the glass membranes of the eye.

(3) When iron comes in contact with cells there is first proliferation and ultimately destruction of the cells.

(4) The common clinical findings in siderotic eyes are pupillary abnormalities, heterochromia, and night blindness. More serious complications such as cataract and retinal degeneration follow.

(5) Foreign bodies of a ferrous nature entering an eye in peacetime are almost invariably magnetic and corrosive.

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