EROSION OF THE TEETH DUE TO SULPHURIC ACID IN THE BATTERY INDUSTRY

BY

D. MALCOLM and E. PAUL

From Chloride Batteries Limited

(RECEIVED FOR PUBLICATION AUGUST 10, 1960)

This paper examines the effects of sulphuric acid on the teeth of workers in the storage battery industry. The manufacturing processes are described. A statistical analysis is given of the findings in a group of workers exposed to acid and an unexposed control group.

It is found that only men exposed to acid mist display erosion of the incisor teeth and that the degree of erosion is classifiable into four groups. The clinical picture of each group is described. There is progressive destruction of the tooth crown from direct impingement of acid droplets. Advanced cases show almost complete loss of crown. Erosion ceases when lip level is reached. The erosion process is painless.

The factors influencing the degree of erosion are investigated. These seem to be: length of exposure, lip level, and concentration of acid in the air.

The differential diagnosis from other causes of tooth destruction is given. The findings of other workers in the field are compared.

Several methods of prevention are discussed.

There are a number of previous descriptions of the effects of various acids on the teeth, under industrial conditions. Few of the writers have had the opportunity of observing a large group of people exposed over a long period.

The effects on the teeth of workers exposed to acid fumes, mists, and dusts have been described previously (Berenzon, 1931; Schour and Sarnat, 1942; Ludewig, 1941; Lynch and Bell, 1947; Dale and McCauley, 1948; Elsbury, Browne, and Boyes, 1951; *New England Journal of Medicine*, 1940).

The present investigation was undertaken to examine the effects of sulphuric acid mist on the teeth of workers in the battery industry. The processes which involve exposure to acid are known as forming and charging.

Description of Processes

Forming.—Lead battery plates are immersed in tanks of dilute sulphuric acid. The plates are then joined together in groups to give a positive and negative pole. Direct current of 110 volts is passed through the circuit, which "forms" the plates.

The tanks measure approximately 3×2 ft. and there are usually 36 tanks to each circuit, giving a very large surface area of acid solution. The department (Fig. 1), which is all under one roof, measures approximately

120×40 yds. Three jack roofs running the full length of the department give good natural ventilation. Air inlet is through side windows and doorways. No successful forced draught has been possible, due to acid corrosion of equipment and the very large area which has to be covered.

During the forming process, small gas bubbles carry a spray of acid mist into the atmosphere (Fig. 2). The concentration of the mist in the department varies with weather conditions, being greatest when there is no wind and when the atmosphere is damp and foggy.

Charging.—This process consists of filling finished batteries with acid and charging them by means of direct current.

The process is similar in effect to forming, but the fact that the battery cells now have lids reduces the acid concentration in the air and it never amounts to a visible mist as it does in the forming department.

Acid Concentrations

Forming.—The mist is a mixture of dilute sulphuric acids of specific gravity varying from 1.020 to 1.100.

The amount of acid in the air, expressed as pure sulphuric acid, varied from 3.0 mg. to 16.6 mg./cu.m. air. These measurements were made on a dry day with low relative humidity, using "teepol" and ebonite sheets. The amount of acid present on a cold humid day often exceeds 16 mg./cu.m. air.

FIG. 1.—Forming shed, showing tanks with ebonite covers in position.

Charging.—The specific gravities of the acids used in charging are higher than in forming and are mostly about 1.265.

The amount of acid in the atmosphere expressed as pure sulphuric acid varies from <0.8 mg. to 2.5 mg./cu.m. air.

The standard error of the method used is $\pm 25\%$.

Method of Survey

The entire staffs of the forming and charging departments, 160 men, were examined. Those having any standing anterior teeth were then re-examined in greater detail, paying close attention to the effect on all teeth, the degree to which each tooth was affected, oral hygiene condition, decayed, missing, and filled (D.M.F.) rates, relation of resting lip levels to the level of erosion, breathing habits, and medical history, if relevant.

A control group of 117 men consisted of all the men in two other departments, free from acid mist or any other industrial dental hazard. These two departments were Inspection, where the component parts of batteries are inspected, and Packers, where completed batteries are packed for despatch. This group was statistically comparable, being of similar mean age, age spread, and social and financial status to the forming and charging groups.

In measuring the degree of erosion, any assessment of the amount of tooth loss must be empirical, as the original dimensions of the affected teeth are unknown.

At the preliminary examination, the degree to which the teeth were affected seemed to fall roughly into four groups and the following classification was therefore adopted for the second examination:

(a) *Attrition*.—Some cases showed loss of tooth substance caused by traumatic occlusion or attrition of the anterior teeth caused by lack of posterior teeth and failure to wear partial dentures.

(b) *Etching* of the labial enamel without loss of tooth substance.

(c) *Group 1 Erosion*: loss, not exceeding 0.2 (2 mm.) of incisal enamel.

(d) *Group 2 Erosion*: loss of 0.2 to 0.5 of tooth crown.

(e) *Group 3 Erosion*: loss of more than 0.5 of tooth crown.

Once Group 1 Erosion has been reached the anterior teeth are no longer in occlusion and attrition of the incisors will not take place.

Of the men from the forming department who had full dentures, a number gave a clear history of erosion prior to extraction. As such history was based on hearsay evidence only, these cases could not be classified with accuracy and so were not included for statistical analysis.

Consideration of the incidence of erosion, etc. among the three groups must naturally be restricted to men with teeth. Thus, of the 63 men at risk in forming only six were free from etching, erosion, or attrition; whereas 33 of the 44 men at risk in the

control group did not have any of these defects. This difference is highly significant ($p < 0.0001$).

Only men who had been exposed to acid mist suffered from etching or erosion of the teeth and only men from the forming department had either Group 2 or Group 3 Erosion (Table 2). Of the 63 men in this department with teeth, 55 had etching or erosion compared with seven of the 15 men in the charging department, a significant difference ($p < 0.01$).

TABLE 1
FINDINGS AMONG THE FORMING, CHARGING, AND CONTROL GROUPS

Condition of Teeth	Forming		Charging		Controls	
	No.	%	No.	%	No.	%
Dentures	66	51.2	16	51.6	73	62.4
Erosion, etching, and attrition	57	44.2	9	29.0	11	9.4
No erosion, etching, or attrition	6	4.6	6	19.4	33	28.2
Total in group	129	100.0	31	100.0	117	100.0
Mean age in years	47.6		43.4		45.0	
Standard deviation	11.3		12.3		10.2	

TABLE 2
EROSION, ETCHING, AND ATTRITION IN FORMING, CHARGING, AND CONTROL GROUPS

Condition of Teeth	Forming (No.)	Charging (No.)	Controls (No.)
Not affected	6	6	33
Attrition	2	2	11
Etching	13	4	0
Group 1 erosion	16	3	0
Group 2 erosion	16	0	0
Group 3 erosion	10	0	0
Total number with teeth	63	15	44

TABLE 3
ORAL HYGIENE AND DEGREE OF EROSION IN MEN IN FORMING DEPARTMENT

Oral Hygiene	No Erosion	Degree of Erosion				Total
		Etching	Group 1	Group 2	Group 3	
Good	1	7	2	1	3	14
Fair	1	2	6	6	5	20
Poor	6	4	8	9	2	29

TABLE 4
DEGREE OF EROSION, AGE, AND LENGTH OF EXPOSURE OF MEN IN FORMING DEPARTMENT

	No Erosion	Etching	Group 1	Group 2	Group 3	Dentures
No. of men	8	13	16	16	10	66
Mean age (years)	48.1	35.1	40.5	43.9	44.5	47.6
Mean exposure (years)	14.6	4.9	7.1	12.3	16.6	21.3

In addition to the groups listed in Table 1, a small group of seven men transferred from the forming

FIG. 2.—A forming tank, showing "formation" of plates in acid solution.

department of a subsidiary factory, was examined. One had dentures, three displayed Group 2 Erosion, and three Group 3 Erosion. This group had a mean length of exposure of five years, which is far less than at the main factory (Table 4).

The Clinical Picture

The clinical picture is typical. The teeth affected were invariably the centrals and laterals on their labial surfaces. Canines were affected to a much smaller extent. No effect was observed on premolars, molars, or the lingual surfaces of any anterior teeth. Upper and lower teeth were affected in equal numbers.

The initial lesion is an etching of the labial surface of the enamel below the lip-line, *i.e.* in the incisal one third of the tooth crown. This gives a dull ground-glass appearance barely visible to the naked eye, but with a sharp line of demarcation from the normal shiny enamel. This is quite different in appearance from the erosion of enamel which precedes cervical caries and which is chalky in both colour and texture, grossly pitted, and invariably at the gingival third of the crown.

Etching is then followed by loss of tooth substance, beginning at the mesio-incisal angle of the central incisors and then spreading to involve the whole of the incisal edge. The surface thus exposed may be highly polished or etched. Because of the greater loss of enamel from the mesial angle than the distal and from the labio-incisal than the linguo-incisal, the incisal edge slopes downwards from the mesial to distal and from the labial to lingual. The junction between the labial and incisal surface (the labio-incisal line angle) is also rounded. This is in direct contrast to cases of physiological attrition, in which the angle is sharp. The picture thus presented is typical and almost diagnostic of Group 1 Erosion (Fig. 3).

With the erosion of the incisal edges, a slight degree of anterior open bite is established. Further loss of tooth substance occurs, partly because of direct wear from biting, but mainly because of progressive erosion from direct impingement of acid droplets on to the tooth surface. This is borne out by the fact that early wear takes the incisors out of occlusion and eliminates loss from direct attrition.

As erosion progresses, more enamel is lost from the incisal edge and the dentine begins to show through the thinned enamel as a white fleck. The tooth crown is shortened and, as still more incisal edge is lost, the dentine becomes exposed. This shows as a deeply stained line, which is usually black or brown, between the two enamel plates. The greater loss of enamel at the labio-incisal line angle, together with the shortening of the crown, gives the tooth a bulbous appearance (Fig. 4). In the advanced cases of Group 3 Erosion, there is almost complete loss of the crown and the "incisal" surface is flat, smooth and shiny, and slopes obliquely (Fig. 5). The inner structure of the tooth is plainly visible in oblique section and the dentine is often a dark red-brown colour. Erosion seems to stop completely when lip level is reached.

In 10 cases, a somewhat different pattern was noticed. Erosion seemed to take place simultaneously over the greater part of the labial surface of the incisors, instead of the incisal edge only. This produced a chisel-shaped tooth with a smooth labial surface and sharp incisal edge (Fig. 6). There was no evidence of trauma to the soft tissues or the tongue in these cases.

None of the men affected by etching or any of the degrees of erosion had experienced pain or sensitivity at any stage. This is presumably due to the laying down of secondary dentine in the pulp chamber as erosion progresses. In one case, however, erosion was so rapid that the pulp was exposed and an apical abscess occurred.

Influence of Other Factors

Oral Hygiene.—Oral hygiene was classified as follows: Good—little or no superficial stain; fair—some deposits of calculus present; poor—large deposits of supra- and sub-gingival calculus.

There is no obvious evidence that oral hygiene has an influence on the degree of erosion. Both materia alba and calculus can be dissolved completely *in vitro* by sulphuric acid and it might be assumed that, *in vivo*, the acid spray would dissolve supra-gingival calculus and give a higher standard of oral hygiene. This is not the case, because the acid mist does not reach those parts of the teeth covered by the lips and cheeks and the lingual surfaces of the incisors and it is here that calculus first collects. In people exposed to acid mist, the exposed surfaces of the teeth are invariably clean and free from materia alba as far down as lip levels.

Age and Length of Exposure.—It is evident that the degree to which a man's teeth are affected is directly influenced by the length of time spent in the department, although one man exhibited Group 2 Erosion after only six months; this was a most unusual case. On the other hand, it seems likely that some men are completely immune. Table 4 shows that eight men had no erosion after an average exposure of nearly 15 years, although the average exposure of those showing etching was five years. It should be mentioned that most of the men in the forming department had been working there for several years before the survey was made and may well have exhibited etching soon after starting. This is borne out by later observation on new employees, many of whom exhibited definite etching after three or four months' exposure.

D.M.F. Rates.—The D.M.F. rate is the number of decayed, missing, and filled teeth expressed as a percentage of 32 and is a guide to the degree of resistance to caries. There was no evidence of any relation between this rate and the degree of erosion.

Lip Levels.—The levels of etching or erosion were observed whilst the patients' lips were at normal rest positions, *i.e.* with teeth and lips slightly parted. In all cases there was a sharp line of demarcation between eroded and normal enamel coincident with the lip-line. Men with markedly short lips showed gross erosion.

It does seem that the length of lips has a direct bearing on the degree of erosion. Only the surface of the teeth uncovered by lips and cheeks is affected. The lips provide a direct shield from the acid spray and also bathe the teeth with protective saliva. Thus the teeth beyond the canines are never affected and erosion ceases at lip level. It is also significant that

FIG. 3.—Group 1 Erosion, showing rounding of incisal edge. Note gum recession on 321 exposing cementation.

FIG. 5.—Group 3 erosion.

FIG. 4.—Group 2 bulbous erosion.

FIG. 6.—Group 3 "chisel" type erosion.

erosion seems to begin at the mesio-incisal angle of the central incisors where the lip level is highest.

Previous Medical History.—Only two men gave a history of chronic nasal catarrh sufficient to cause habitual mouth breathing. Obvious mouth breathers are excluded from working in the department.

Concentrations of Acid in the Air.—In the forming department 55 (87%) of the men with standing teeth were affected, whereas in the charging department only seven men out of 15 showed any evidence of attack by acid, with only three showing actual erosion. The acid exposure of the charging group was much less (see above) and so was the degree of erosion. It is probable, therefore, that a certain amount of acid in the air is necessary to cause erosion.

Six men from the forming department were unaffected by acid and did not show attrition. This

could be due either to the resistance of the particular enamel or, alternatively, to these individuals seldom parting their lips and so allowing acid spray to reach the teeth. This factor cannot, of course, be measured.

Dentures.—Some of the men in the forming department stated that, before having total extractions and acquiring dentures, their anterior teeth were eroded. In spite of this, we found that 51% of the men in the forming department had dentures against 62% of the controls. This suggests that erosion of the teeth was seldom, if ever, the sole reason for acquiring dentures. Although the difference is not statistically significant ($p = 0.1$), it is possible that exposure to acid vapour does in fact help to preserve the teeth. It is known that acid dissolves calculus and could thus have improved the self-cleansing of the teeth. Our observations suggest, however, that calculus is only dissolved where erosion takes place and, therefore, only tends to

protect the incisors. It is possible that the erosion, producing smooth shiny areas, renders the incisors self-cleansing and more immune to carious attack. Certainly no caries of anterior teeth was ever observed in any of the affected men.

Discussion

Our observations on this group of men exposed to sulphuric acid mist leave no doubt that the erosion of the incisors is due to the direct impingement of fine droplets of acid. The teeth beyond the canines are not exposed to direct impingement of acid mist and are also more constantly bathed by saliva.

The parts of the incisors which are normally covered by the lips are never eroded and this is the reason why the cervical areas are unaffected, although the enamel is thinnest here.

This type of erosion is similar to that produced in industry by other acids including hydrochloric, nitric, and tartaric. Hydrofluoric acid does not produce erosion despite the fact that, during its manufacture, there is a high percentage of sulphuric acid in the atmosphere (Dale and McCauley, 1948). Hydrofluoric acid affords some protection against sulphuric acid erosion.

The sulphuric acid erosion described is characteristic in appearance. It is easily distinguished from caries, which produces soft circumscribed areas with undermined edges, and from attritions and abrasions of the teeth. The condition attributed to acid erosion by some authors (Thoma and Robinson, 1955) is almost certainly gross cervical caries.

Attrition is commonly seen in persons who have traumatic occlusions. Abrasion of the teeth is commonly seen in pipe smokers and upholsterers, shoemakers, seamstresses, glass-blowers, etc. Both attrition and abrasions can easily be distinguished by their obvious cause, the wear being limited to areas of contact between the teeth, and by the production of shiny facets with sharp margins. This is in direct contrast to the rounded margins seen in acid erosion.

Acid erosion of non-industrial aetiology is not uncommon, the main causes being: regurgitation of vomit (Burket, 1957), medicinal drinking of dilute hydrochloric acid, and excessive consumption of citrus juices and fruit drinks (Finch, 1957; Hicks, 1950; Stafne and Lovstedt, 1947).

These non-industrial erosions differ markedly from the industrial erosions. The lesions produced are shiny, smooth, disc-shaped, shallow cavities affecting principally the cervical areas of the teeth. Hypersensitivity is often a marked feature.

Misch (1923), in a report on industrial erosions in Germany, claims that the condition produces

numbness in the teeth affected and later severe pain. He also claims that the teeth become very brittle. In these respects, our findings differ; we have found no evidence of pain, or even sensitivity to temperature extremes, in any cases at any stage of erosion, and we have never seen any sign of tooth breakage, which one would expect if erosion produced brittleness. We maintain that loss of tooth substance is due to gradual erosion by direct impingement of acid mist on the exposed tooth surfaces.

Prevention

In the forming department, owing to the very large area of some 1,200 acid tanks, each of approximately 3×2 ft. surface area, the task of ventilation is extremely difficult. Attempts have been made to reduce the spray by the use of "teepol". This causes a foam on the top of the acid and the gas bubbles then coalesce in the foam.

Ebonite sheets have been used to cover the tanks and these cause condensation of the spray and the acid then runs back into the tanks. Both these methods have reduced considerably the amount of spray in the atmosphere.

Total enclosure might be possible and an attempt is to be made to see if this is practicable. Ventilation of the department appears to be a major factor in prevention.

The small group of seven men transferred from a subsidiary factory all showed advanced erosion more rapidly, probably because working conditions and ventilation were poor. Similarly, during the war years, when ventilation was of necessity restricted, there appears to have been more rapid erosion.

In some small forming departments in other battery firms, where side walls have been left out of the buildings, there is a lower concentration of acid in the air, due to much better air flow, and little or no erosion is seen. Such construction is, however, impracticable in a large factory.

Protection of the incisor teeth with fitted plastic splints lined with magnesia has been tried. These splints are somewhat uncomfortable to wear for long periods and the men quickly stopped using them.

Alkaline mouth washes do not give any lasting protection and no drinking or chewing is permitted, on account of the lead hazard. The chewing of "oralgene" gum, or alkaline tablets advocated by Hentze (1925) is therefore impracticable. The use of celluloid face-shields is being instituted. This should afford a certain amount of protection by preventing the acid droplets from impinging directly on the teeth. It is felt that the only method of giving direct protection to the teeth is by the use

of a mouthwash or dentifrice which will deposit a protective film on the enamel and remain effective for at least four hours. Several substances are being investigated currently.

We should like to express our thanks to the management of Chloride Batteries Limited, for allowing us to carry out this survey; to the foremen of the departments for their help and particularly to all the men we surveyed, who were so co-operative and gave us so much of their time. We should also like to thank Mr. John Slater of the Chloride Electrical Storage Company Ltd., Research and Development Department for the measurement of the acid concentrations in the atmosphere; and Mrs. White and Miss Clayton for their help in arranging interviews and collecting much of the background information. Finally, we wish to thank Miss I. Dingwall Fordyce, of the Department of Occupational Health of Manchester University, for all her help in the preparation

of the statistics, and the Department of Medical Illustration of Manchester Royal Infirmary for the photographs of the teeth.

REFERENCES

- Berenzon, F. B. (1931). *Brit. dent. J.*, **52**, (1), 22.
 Burket, L. W. (1957). *Oral Medicine*, 3rd ed., p. 199. Lippincott, Philadelphia.
 Dale, P. P., and McCauley, H. B. (1948). *J. Amer. dent. Ass.*, **37**, 131.
 Elsbury, W. B., Browne, R. C., and Boyes, J. (1951). *Brit. J. industr. Med.*, **8**, 179.
 Finch, L. D. (1957). *Brit. dent. J.*, **103**, 280.
 Hentze, A. (1925). 'Die Beziehungen der Zahnheilkunde zu Gewerbekrankheiten'. *Zahnärztl. Rdsch.* XXXIV Nos. 45 and 46.
 Hicks, H. (1950). *J. Amer. dent. Ass.*, **41**, 38.
 Ludewig, W. (1941). *Arch. Gewerbepath. Gewerbehyg.*, **11**, 296; and in *J. industr. Hyg.* **25**, Abstracts, p. 35.
 Lynch, J. B., and Bell, J. (1947). *Brit. J. industr. Med.*, **4**, 84.
 Misch, J. (1923). *Lehrbuch der Grenzgebiete der Medizin und Zahnheilkunde*, 3rd ed. Vogel, Leipzig.
New Engl. J. Med. (1940). **223**, 303.
 Schour, I., and Sarnat, B. G. (1942). *J. Amer. med. Ass.*, **120**, 1197.
 Stafne E. C., and Lovestedt, S. A. (1947). *J. Amer. dent. Ass.*, **34**, 586.
 Thoma, K. H., and Robinson, H. B. G. (1955). *Oral and Dental Diagnosis*, 4th ed., pp. 190-197. Saunders, Philadelphia.