Occupational Dental Erosion

By

WorkSafeBC Evidence-Based Practice Group

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WORKSAFE BC WORKING TO MAKE A DIFFERENCE **Clinical Services - Worker and Employer Services**

About this report

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The Evidence-Based Practice Group was established to address the many medical and policy issues that WorkSafeBC officers deal with on a regular basis. Members apply established techniques of critical appraisal and evidence-based review of topics solicited from both WorkSafeBC staff and other interested parties such as surgeons, medical specialists, and rehabilitation providers.

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Executive summary

Dental erosion is the chemical wear of the hard tissues of the teeth (dentin and enamel) due to chronic and/or frequent exposure to internal (i.e. gastric or eating disorders, vomiting, alcoholism, salivary hypo-function) and/or external (i.e. environmental, occupational, dietary) acids.

Epidemiologic studies report a wide range of prevalence (5% to 50%) varying across different age and occupational groups, geographic areas, and cultures. Distinguishing dental erosion from other types of tooth wear (attrition and abrasion), specifying underlying etiologic factors, and recognizing this condition in its early stages can be challenging. Due to workplace acid exposures (sulfuric, hydrochloric, nitric, tartaric, chromic, phosphoric, or acetic acids), workers in certain occupations (i.e. in mineral, battery, chemical, tin, dyestuff, fertilizer, and also metal (galvanizing, plating, silicone sealing, acid pickling) industries) are at higher risk of developing dental erosion. The objective of the Evidence-Based Practice Group (EBPG) of WorkSafeBC in undertaking this systematic review was to increase awareness of this preventable occupational disease, particularly in relation to airborne acid exposures in workplaces, and to help inform decisions during coverage and adjudication processes.

To better understand the relationship between dental erosion and occupational acid exposure, we searched the medical/dental literature using appropriate systematic review searching protocols. The search was conducted through PubMed, EMBASE, and the Cochrane Library, including studies published until November 2009. We included all study designs and only excluded studies if they were not in English, were exclusively on internal acid exposures, or were conducted solely with children. After reviewing the abstracts we selected relevant studies and hand-searched their reference lists for additional studies. We critically appraised 22 studies, which focused on dental erosion in relation to workplace airborne acids. One of these was a case-control study; 18 were cross-sectional studies; and 3 were case series/case reports. We also included 1 cross-sectional study on professional swimming (HCl exposure) and 2 on wine tasting (various organic acid exposures). Based on EBPG criteria, all 25 studies were rated as providing low quality evidence (Levels 3 and 4). (Appendix 1)

According to the appraised studies on dental erosion and workplace airborne acid exposure:

- dental erosion usually occurs at the labial surface of anterior teeth
- canines are affected less than central and lateral anterior teeth
- areas unprotected by lips/cheeks are at higher risk of developing erosion
- prevalence is higher in battery and galvanizing workers
- significant correlation exists between ‘duration of acid exposure’ and ‘severity of erosion’

According to the appraised studies on dental erosion and acid exposures in professional swimmers and wine tasters:

- dental erosion usually occurs at labial surfaces of anterior teeth
- symptoms related with dental enamel erosion are seen more in professional swimmers
- ‘severity of erosion’ is higher with ‘longer years of occupational exposure’

Identification of contributing etiologic factors is important for appropriate management of dental erosion. If dental erosion is recognized at early stages, further damage can be minimized. Preventive measures pertaining to lifestyle and work environment, and treatment of any underlying medical conditions, may change the ultimate outcome.

The current literature consists of studies providing low quality evidence for the association between occupational acid exposure and dental erosion. Higher quality studies are needed to better guide evidence-based dental practices and compensation policies. Until then, the EBPG of WorkSafeBC recommends that the “arising out of and in the course of employment” rule to be an appropriate basis of any assessment when concluding on “occupational hazard(s)” as the main contributing factor(s) of dental erosion. Management, treatment, and compensation decisions should follow accordingly.

Introduction

Tooth wear, the loss and destruction of tooth surface due to mechanical or chemical processes, affects all age groups. It can manifest in three different forms: erosion, attrition, and abrasion. Once dental erosion (chemical process) occurs the hard tissue of the tooth is softened and susceptibility to mechanical forces, which lead to attrition and abrasion, increases.[1-9] Dental erosion usually manifests with related disfigurement, inconvenience and functional disability.[3] Epidemiologic studies suggest that 5 to 50% of the general population have dental erosion.[10] Prevalence varies across different age and occupational groups, geographic areas, and cultures. It changes over time as well.[10,11] For example, in Korea, the prevalence of occupational dental erosion was reported as 8% in 1993 and 11.3% in 2003.[12] Unfortunately, many individuals do not recognize the condition and do not seek help until after aesthetics are affected or they suffer from hypersensitive teeth.[2] Dental erosion patients can face serious functional problems as well. For example, some individuals may develop temporomandibular joint dysfunction, which leads to impaired mastication.[11,13] If dental erosion is recognized at an early stage, further damage can be minimized by initiation of preventive measures pertaining to life style and work environment, and by treating the process which may be the underlying cause. Identifying the contributing etiologic factors is one of the first steps in appropriate management.

Background

The problem

Dental erosion is a chronic, progressive type of tooth wear, which destroys dental hard tissues (enamel and dentin). Erosion is the result of a chemical process, with no bacterial involvement, [5,10,11,14,15] and is due to chronic and/or frequent exposure to internal or external acids.[6,14,16] In the International Classification of Diseases (ICD), erosion of teeth is coded as 521.3 (ICD-9) and K03.2 (ICD-10).[17,18] Although some investigators prefer using the term ‘corrosion’ instead of ‘erosion’,[19] it still implies the chemical wear of dentition. Distinguishing dental erosion from attrition (wear of dental tissue by tooth-to-tooth contact) and abrasion (wear of dental tissue by exogenous substances) can be difficult.

Attrition emerges with flattened cusp tips and incisal edges; it is seen more frequently in the elderly and in developing countries.[20] Molars are most frequently affected.[20,21] Enamel and dentin tissues are involved fairly equally.[19] Attrition usually displays as matching wear on upper and lower occluding surfaces[22] with both arches fitting together.[23] Tooth loss by attrition is higher in areas of reduced supporting teeth[14] and the most severe attrition is observed in bruxism cases.[19]

Abrasion, which is the physical wear of tooth surface due to mechanical or frictional forces from exogenous agents,[6,14,128] usually affects premolars and molars.[20] As the dentin and cementum are more susceptible to abrasion,[4,14] a rounded or V-shaped groove develops between the gingivae and the enamel of the crown.[14] Abrasive toothpastes and aggressive toothbrushing are the most common factors related to abrasion.[4,6,14]

The occlusal loading forces affecting teeth, especially in the cervical regions, may become stressors and lead to crescent formation along the cervical line where the enamel layer is inherently fragile. Some investigators call the resulting microstructural tooth substance loss 'abfraction'.[19] However, others argue that there are not sufficient clinical studies on abfraction to justify that position and that it is still a theoretical concept.[24,25] Bartlett explained the wear of the cervical margin to be the result of the combined effects of erosion, abrasion, and attrition.[24] Khan found that shallow cervical lesions were more common in occlusal erosion, whereas wedge-shaped lesions were equally common in occlusal erosion and attrition.[26]

Erosion can affect both the enamel and dentin tissues, and both the occluding and non-occluding surfaces of teeth. When acids touch the surface, they diffuse through the acquired pellicle (an organic film made of salivary proteins and glycoproteins) and the hydrogen ion of the acid dissolves the enamel crystal. First the prism sheath area, and then the prism core area, dissolves. This leads to the typical honeycomb appearance at the early stages of erosion. Later, acid diffuses into the interprismatic areas of enamel, and eventually into the region below the surface.[2,27,28] Tooth surface becomes softened and then diminishes.[27] Once the softened tooth surface has faced mechanical insult (toothbrushing, etc.), it cannot remineralize.[6] In vitro studies have shown that erosion in dentin can occur even at pH levels as high as 6.0 and that compared to enamel, chances that dentin will remineralize are lower.[29] The first dentin area to be affected is peritubular dentin. Intertubular areas follow, leading to rough, porous surfaces. The process may eventually involve pulp tissue.[28] During a clinical examination for dental erosion, a polished (silky-glazed) appearance of enamel, broad concavities within the enamel surface, cupping of occlusal surfaces due to dentin exposure, increased incisal translucency, and hypersensitivity are common findings.[10] The margins of the erosive defects are usually rounded.[22] The edges of the amalgam restorations may be elevated, and incisor teeth are frequently shortened and chipped.[23,30] Patients with active dental erosion have unstained tooth surfaces[2] and are more likely to suffer from hypersensitivity.[14,28] Since cupping and grooving of occlusal/incisal surfaces may also be seen in abrasion alone, Ganss argues that the shallow defects of smooth surfaces (coronal from the enamel-cementum junction) are more specific and valuable in the diagnosis of dental erosion.[7,31] He also argues that cupping of cusps in younger subjects is likely to be associated with erosion, whereas it would have little diagnostic value when observed in older subjects.[7] Nevertheless, in any patients who display tooth loss disproportionate to their age, dental erosion should be suspected.[7,14]

Tooth wear always warrants a multifactorial approach. Three different types of wear (erosion, abrasion and attrition) can exist simultaneously[9] and can make diagnosis and management a challenge. They can also act sequentially, synergistically, or additively.[32] Stage of the tooth wear is also important in diagnosis. For example, dental erosion related to diet, affecting enamel only, frequently goes unrecognized; whereas when dentin is exposed, erosion will likely be recognized early (due to its yellower colour and associated symptoms of hypersensitivity to temperature change).[33] Although erosion occurring within certain areas of the tooth suggests different exposures (such as inciso-labial erosion due to industrial acids[3,21,34-42] or palatal surface erosion of upper incisors, canines, and premolars due to gastric acids[21,28,30,43,44]) it is generally not reliable in determining the cause of the erosion.[10,28,30]

Intrinsic and extrinsic acid loads determine the acidity levels of the oral cavity. If they lower the pH beyond 5.5, which is the threshold level for healthy enamel,[15,28] dental erosion may be triggered. When the acidic origin is unknown, it is frequently labeled dental erosion of 'idiopathic-origin'.[5] Intrinsic factors that lead to excess acid are: gastric disorders (gastroesophageal reflux, regurgitation/rumination), eating disorders (anorexia nervosa, bulimia), vomiting due to other conditions (alcoholism, pregnancy, gastrointestinal or nervous system disorders, diabetes), salivary hypo-function (decreased salivary flow, pH, and buffer capacity), and dry mouth due to autoimmune or other diseases.[13,16,45-47] There is also a long list of extrinsic factors which increase acid levels in the oral cavity. One group is environmental acid exposures (sulfuric, hydrochloric, nitric, tartaric, chromic, phosphoric, acetic acids) occurring during a wide range of industrial processes such as mineral, battery, chemical, tin, or dyestuff manufacturing; or galvanizing, plating, silicone sealing, and acid pickling of metals.[3,13,27,34,42,48] Winemakers/wine tasters are usually exposed to tartaric, malic, lactic, citric, succinic, and citramalic acids[34,49,50] and competitive swimmers are exposed to low pH levels in gas-chlorinated swimming pools.[51-55] Another occupational factor, although not acidic, is the exposure of workers to proteolytic enzymes in the biotechnological and pharmaceutical industries.[56] In vitro studies have shown that proteolytic enzymes are able to dissolve both the enamel and dentin layers of teeth.[57] There are extrinsic factors related with life style[15] as well; these include consumption manner, duration, type, and amount of acidic foods and beverages (citric fruits, acidic snacks, soft drinks, sports supplement drinks, and alcohol abuse),[2,9,10,14,43,45,58-61] and oral hygiene habits (type of dentifrices being used(toothpaste, tooth powder or mouthwash), time between acidic food/drink consumption and brushing, and fluoride use).[2,42] Intake of acidic medications like chewable Vitamin C or hydrochloric acid supplements,[10,13,42,62,63] medications which lead to hyposalivation or dry mouth, such as antidepressants and β-blockers,[43,63] medications causing vomiting as a side effect, such as digitalis, estrogen, chemotherapeutic agents, diuretics, and ferrous sulfate,[43,46] powder forms of asthma medications, which have lower pH levels compared to aerosol forms,[13,63] and amino-acid supplements used for the treatment of phenylketonuria[13] are other extrinsic factors which can lead to dental erosion. As Lussi points out, knowledge, education, socio-economic status, habits, and general health of the person are all factors of possible influence.[2]

When diagnosing dental erosion, interactions amongst these various factors – either intrinsic or extrinsic – need to be taken into account as well. Some factors may play a role in the initiation of the erosive lesion, whereas others might affect the progression. While some factors might act simultaneously, others may be sequential. Even in those individuals who experience the same acidic exposure (same acidity), the intensity of the erosive response varies depending on numerous interplaying factors.[2] Biological makeup of the oral cavity (dental and soft tissue anatomy, tooth structure, movement patterns of the soft tissue, pellicle formation, and salivary factors) should be taken into account.[2,42] Salivary factors include pH, phosphate and calcium concentration, fluoride content, flow rate, and buffering capacity.[10,28,64,65] Higher unstimulated flow rate[27,45] and buffering capacity[27,66,67] of saliva are particularly important in terms of protective effect. Young points out that the normal protective role of saliva in the mouth seems to be site-specific, being higher in areas close to salivary glands.[68]

Once dental erosion develops and tooth surface is lost, arising clinical problems may range from discomfort (due to distorted appearance and/or dysfunction of the dentition)[13,16] to dentin hypersensitivity[4,13,20] or even to loss of teeth.[69] In this systematic literature review we are focusing on extrinsic factors related to environmental/occupational acidic exposures that may cause dental erosion. Specific attention is paid to studies on working populations exposed to acidic gases, vapours, and fumes at various workplaces.

Measuring the level of acidic exposure

When measuring the level of intrinsic or extrinsic acidic exposures that lead to dental erosion, we sometimes make assumptions and use proxy measures. For example, a vegetarian diet is believed to involve higher acidic food consumption. Therefore, we presume all vegetarians to be at a higher risk of developing dental erosion (without having individual level exposure data). Another example: although the oral cavity pH is not measured each time somebody vomits, it is accepted that the increase in hydrochloric acid level due to vomiting could lead to dental erosion. Therefore, the frequency of vomiting is used as a proxy measure to define the level of acidic exposure.

If studies on dental erosion due to intrinsic factors (gastric/eating disorders, salivary hypo-function, systemic diseases leading to dry mouth, etc.) collect individual acid exposure data, they usually measure the pH level of the esophagus and/or oral cavity.[45,47,66,67] Studies with dietary acids (an external factor) often include information on the acidity of the foods and drinks, as well as the frequency, duration, and manner of consumption.[4,13,70] In any case, studying dental erosion before and after an acidic exposure in a clinical setting is challenging. First of all, the study subjects have generally already had significant acidic exposure prior to the study. Secondly, even if an appropriate before/after clinical study could be undertaken, study duration needs to be sufficiently long to capture the slow erosive development process.[11,23,28] This probably helps explain why in vitro studies are becoming more popular.[71-77]

In the case of other external acid exposures, data is usually collected at the environmental level, for example, levels of hydrochloric acid in swimming pools, acid levels of wines produced in a winery, or airborne acid levels in the manufacturing settings of the mineral, battery, chemical, and metal industries. To regulate acid exposures in these settings, the Threshold Limit Values (TLVs) of hazardous chemical and physical substances, set by the American Conference of Governmental Industrial Hygienists (ACGIH) are generally used. However, the use of TLVs is not a standard practice across the globe. Some other limits used include: Permissible Exposure Limits (PELs) (U.S. Occupational Safety and Health Administration (OSHA)),[78] Recommended Exposure Limits (RELs) (U.S. National Institute for Occupational Safety and Health (NIOSH)),[79] Maximum Concentrations (MAKs) (Deutsche Forschungsgemeinschaft (DFG)), Workplace Exposure Limits (WELs) (U.K. Health and Safety Commission), and Occupational Exposure Limits (OELs) (South African Department of Labour and the Department of Minerals and Energy).[80] As one example, the threshold level (as TWA: Time Weighted Average) for sulfuric acid is 0.2 mg/m^3 in TLVs, 1 mg/m^3 in PELs and RELs, and 0.1 mg/m^3 in MAKs.[80] In the chemical information database (CHEMINFO) of the Canadian Centre for Occupational Health and Safety (CCOHS) exposure guidelines for hazardous substances, the limit values are given in ACGIH TLVs and OSHA PELs.[81] The International Occupational Safety and Health Information Centre (CIS) of the International Labour Organization (ILO) lists hazardous occupational chemical exposure limits only in TLVs and MAKs.[82] Some studies have shown dental erosion to occur even at acid levels below the recommended threshold levels.[36] Reduction of the accepted threshold limit values to safer levels that consider dental erosion as a health problem may be useful.[34,36,83]

Measuring the level of erosion

Unfortunately, there is no standard method to measure dental erosion. Different definitions, parameters, and terminology used by various researchers across the world confound the interpretation of studies.[33] Similarly, there are various grading indexes used during clinical dental examinations and studies, and these indexes are not comparable.[84] Some consider only the depth of wear; some consider both the depth and the surface aspects of the wear. For example, ten Bruggen classifies dental erosion into four groups, with an additional starting grade called ‘etching’ (dull, ground-glass appearance of enamel surface, no loss of contour, includes plates 1 and 2). ‘Grade 1’ is loss of enamel (plates 3 and 4); ‘grade 2’ involves dentin loss (plates 5 and 6); ‘grade 3’ involves loss of secondary dentin (plates 7, 8, and 9); and ‘grade 4’ is when the erosion reaches the pulp.[3] In comparison, Eccles classifies dental erosion more simply in three groups: ‘class I’: loss of enamel surface only (smooth, glazed appearance); ‘class II’: involvement of less than 1/3 of dentin; and ‘class III’: involvement of more than 1/3 of dentin. In this classification of non-industrial tooth erosion he also assigns letters in classes II and III (with dentin exposure): ‘a’: labial; ‘b’: lingual or palatal; ‘c’: occlusal or incisal; and ‘d’: multi-surface.[14] In his original 1979 paper, the letters were assigned only in class III, for the most severe erosion.[85] The tooth-wear index (TWI) developed by Smith and Knight aims to provide guidance to clinicians in distinguishing ‘normal’ and ‘pathologic’ tooth-wear. It sets maximum levels of acceptable tooth-wear for each age group. Four surfaces (cervical, buccal/labial, lingual/palatal, occlusal/incisal) of each tooth are evaluated (4x32=128 surfaces per patient) and recorded electronically. TWI has five grades: ‘grade 0’: no enamel loss, no contour change; ‘grade 1’: loss of enamel surface, minimal loss of contour; ‘grade2’: loss of enamel + exposure of dentin in less than 1/3 of the surface, defect less than 1mm deep; ‘grade 3’: loss of enamel + exposure of dentin in more than 1/3 of the surface, defect 1-2mm deep; and ‘grade 4’: complete loss of enamel, or pulp exposure, or exposure to secondary dentin, defect deeper than 2mm.[86] According to a review paper by Berg-Beckhoff, the most frequently used index for adults in the period of 2000-2006 was the Smith and Knight TWI Index, with the major shortcoming of this index being that it is a general toothwear index, lacking diagnostic criteria for erosion.[84] Johansson grades the severity of dental erosion into five groups, using a modified version of Eccles’s ordinal scale. ‘Grade 0’: no visible enamel changes; ‘grade 1’: smooth enamel, partially or totally vanished developmental structures; ‘grade 2’: no dentin exposure, faceting or concavity within the enamel; ‘grade 3’: dentin exposed surface ≤ 1/3, changes in macromorphology; and ‘grade 4’: dentin exposed surface ≥1/3 or visible pulp.[87] About a decade after the recommendations from the international Europe workshop on dental erosion (1995) were published, a new scoring system for dental wear, which can be used for both clinical and epidemiological work, was introduced. This new scoring system was termed the Basic Erosive Wear Examination (BEWE).[88] The BEWE is based on sextant (single 1/6 portion of all teeth) technique, which includes full mouth examination, but records only the most severely worn surface of each sextant. It assesses wear on coronal surfaces only and estimates severity by diameter and depth (not by dentin involvement).[88] The scores in the BEWE are: ‘0’: no erosive tooth wear; ‘1’: initial loss of surface texture; ‘2’: distinct defect, hard tissue loss <50% of the surface area; and ‘3’: hard tissue loss ≥50% of surface area. The sum of the highest scores from each sextant is added up to a BEWE score. This cumulative score guides the clinician about the risk level of the patient (none: ≤ 2; low: 3-8; medium: 9-13; high: ≥14). The BEWE was expected to be a good tool for screening studies,[89] however, Berg-Bechoff points out that the gold-standard instrument (an individual-based index), and the population-based short version of this instrument, should be measuring the same construct – “tooth erosion” – and efforts have to be made for an internationally agreed upon index.[84]

Besides these dental erosion classifications based on clinical findings, some novel techniques such as non-contacting surface profilometry, scanning electron microscopy (SEM), and transmission electron microscopy (TEM) are also in use. These techniques are able to detect tooth surface loss measured in microns and are usually performed during in vitro studies.[73-76] Measurement of microhardness (SMH),[28,76] loss of surface contour (proflometric analysis), and surface porosity are other techniques being used for measuring the level of tooth surface loss.[28] Lussi states that in order to reveal dentin involvement, some disclosing agents (i.e. some specific dyes) might be needed.[90]

Recently, more technology-based methods have been developed to measure dental erosion in vivo. For example, Mitchell et al. developed an erosion detection system based on replica mappings and mathematical surface matching. They mapped the palatal surfaces of the maxillary central incisors of 100 study subjects and after nine months detected erosion of more than 50µm in ¼ of the studied teeth.[91]

Work-related dental erosion

In his 1996 paper, Lussi stated that "exposures to acidic environments are hardly seen nowadays".[92] However, despite the general downward trend in occupational exposures, Symanski et al. reported that about 20% of the 'level of exposure' data still displays an upward trend. They observed that the increase was more pronounced in carcinogen exposures and metals, compared to other types of contaminants.[93] We cannot tell exactly how much of this upward trend was attributable to acid contaminants, as the paper does not present individual contaminant data. However, sulfuric acid, hydrogen chloride, nitrogen dioxide, and sulfur dioxide were amongst the aerosols, gases, and vapours listed in the paper.

As mentioned before, workers in the mineral, battery, chemical, tin, and dyestuff manufacturing industries, along with those in the metal industries doing galvanizing, plating, silicone sealing, and acid pickling, are more likely to be exposed to airborne acids such as sulfuric, hydrochloric, nitric, tartaric, chromic, phosphoric, and acetic acids.[3,13,27,34,42] These acids may have irritant effects on mucous membranes and epithelia (such as the respiratory tract, eyes, or skin) and chemical corrosive effects on teeth.[94-97]

Dental erosion due to industrial airborne acids has a common clinical presentation. In general, erosive lesions are located at the incisal portions of the upper and lower anterior teeth, particularly the centrals.[14] These labio-incisal lesions have rounded margins and severe loss is usually limited to the anterior teeth.[3] On the other hand, lesions of abrasion and attrition would have sharp margins, erosion due to acidic drinks and foods (rather than airborne acids) would affect all parts of the teeth (not only the anterior),[3] and erosion due to intrinsic factors (like acid reflux or vomiting) would develop at the palatal surface of the upper teeth and at the occlusal surfaces of both upper and lower teeth.[14] Workplace exposures, which cause dental erosion, are not limited to the airborne acids of industrial settings. For example, the acid concentration of gas-chlorinated swimming pools is important for professional swimmers, who use the pool more frequently and spend longer hours in the pool compared to recreational swimmers. The standard pH recommended for swimming pools is 7.2-8.0;[52,54] however, there are often pools which do not follow this recommendation. When the acid level of a pool is high, a common finding on affected teeth is a honeycomb-like etch pattern.[51] Soon, rapidly developed general erosion makes up the clinical picture.[53] Other occupational exposures occur during wine production.[49,50,55,98-100]

Wine tasters, sometimes performing over 100 tastings per day,[55] are highly exposed to a range of organic acids such as tartaric, malic, lactic, succinic, and citric acids.[34,49,50] Additionally, with all the swirling and rinsing during tasting, they are exposed to acids for a longer time period than a leisure drinker. This leads to tooth loss on the maxillary labial and incisal surfaces, as acid is retained longer in this region and clearance also takes longer.[55,100] However, in his review on occupational dental erosion, Wiegand argues that there are few clinical studies and limited data on wine tasters and competitive swimmers for making inferences about the potential risk of dental erosion in these occupations.[34] Also, studies on proteolytic enzymes and dental erosion are limited. A study by Westergaard et al. found a statistically significant association between proteolytic enzyme exposure and Class V restorations. However, they did not observe the same association with respect to the other two outcomes, which were facial and lingual erosion. Nonetheless, the authors stated that proteolytic enzymes lead to tooth loss, which requires treatment.[57] Another occupation with high acidic exposure risk is laboratory work requiring pipetting acids by mouth.[42]

When dental erosion is suspected to result from acidic exposures in the work environment, any study on this population should also address possible confounders and effect modifiers. If possible, biological make up of the patient's oral cavity (including the salivary properties, etc.), dental care practices (regular visits to dentist, toothbrushing, etc.), eating/drinking habits (acidic drinks, excessive citrus fruits, etc.) along with specific medical disorders and medication use (acid reflux, eating disorders, antidepressants, etc.) should be reviewed and controlled for during any data analysis.

Studies on work-related acidic exposures and dental erosion

Table 1. Airborne acidic exposures and dental erosion

Study	Study setting / industry / job	Study design	Study Subjects	Exposure (Acid type)	Measuring Exposure	Dental Erosion Classification	Measuring Dental Erosion	Statistical Analysis	% with Dental Erosion (exposed / unexposed)	Dental Erosion / Exposure Duration	Dental Erosion / Age	Dental Erosion / Location	Risk
Amin WM 2001[48]	Phosphate industry and battery factory workers in Jordan Survey (from December 1999 to April 2000)	Cross-sectional, comparative study	Workers from Aqaba and Hassa and workers from Amman 68 from phosphate industry (37 acid workers & 31 controls, mean employment 9.5 years); 39 from battery factory (24 acid workers & 15 controls, mean employment 11.3 years)		To monitor stack gas, alkali absorption method was used (No other environmental monitoring) Questionnaires, interviews (medical/dental histories, dietary habits, oral hygiene practices, work conditions, dental symptoms)	Dental erosion index (based on Smith & Knight index and Johansson index). Only labial & lingual surfaces of maxillary anterior teeth were recorded [0: no loss of enamel, 1: enamel loss, 2: faceting and concavity within the enamel, 3: less than 1/3 dentin loss, 4: more than 1/3 dentin loss or pulp visibility through dentin]	Clinical examination (by two examiners who were blinded to the exposure status of the workers)		Most common complaints: tooth hypersensitivity (80%) and dry mouth (77%)	Severity of erosion and proportion of subjects with erosion increased with longer exposure time		Labial surfaces were more affected (for people without gastric problems); central incisors more affected than lateral incisors	Significantly higher risk of dental erosion in acid workers compared to controls (P<0.05)
Arowojolu MO 2001[35]	Nigerian Motor Mechanics/ Technicians Association Adeoyo Unit 1 Zone, Ibadan, Nigeria	Cross-sectional, comparative study	105 workers, responded to questionnaire (67 auto-mechanics, 38 battery chargers & their apprentices)		Questionnaire		Dental examination		The percentage of number of teeth affected by erosion was 3.2 (23/712) for auto-mechanics and was 41(159/388) for battery chargers (P<0.05)			Erosion took place mainly on the labial surface of the index teeth examined	3.2% of teeth of auto-mechanics and 41% of teeth of battery chargers had dental erosion (P<0.05)
Bamise CT 2008 (Dental erosion…)[101]	Obafemi Awolowo University, Restorative Department, Nigeria	Case report	24-year-old battery technician (roadside battery charger)	Lead-acid rechargeable battery solution	History taking	Grossly damaged dental hard tissue	Clinical examination		Complaints: chipping of the teeth, tooth sensitivity, inability to chew properly			Extensive cupping & wear facets in posterior surfaces of maxillary molars, destruction higher in mandibular anterior than in maxillary anterior teeth	

Study	Study setting / industry / job	Study design	Study Subjects	Exposure (Acid type)	Measuring Exposure	Dental Erosion Classification	Measuring Dental Erosion	Statistical Analysis	% with Dental Erosion (exposed / unexposed)	Dental Erosion / Exposure Duration	Dental Erosion / Age	Dental Erosion / Location	Risk
Chikte UM 1999[36]	South Africa, electro-winning facility (zinc)	Cross-sectional, single-blind study	103 acid exposed workers (mean age 31.4 & mean length of service 4.2 years) 102 unexposed workers (similar in terms of age & length of service)	Sulfuric acid mist (H_2SO_4)	Questionnaire Measurement of acid level 3 times a week: In exposed, H_2SO_4 was 0.3mg/m^3 – 1mg/m^3 In unexposed, H_2SO_4 was 0.1mg/m^3 – 0.3mg/m^3	Eccles & Jerkins' classification: 0 (no clinical evidence); I (enamel only, loss of surface); II (dentin involved in less than 1/3 of the tooth surface lost); III (dentin involved in more than 1/3 of the surface lost)	Clinical examination	Odds ratio calculations, Chi square tests, etc	Exposed workers more likely to experience tooth surface loss compared to unexposed workers OR= 11.4 More exposed workers had pain & sensitivity ($P<0.02$)	Length of service was a statistically significant factor increasing tooth surface loss in the unexposed (H_2SO_4: 0.1mg/m^3 – 0.3mg/m^3)	In the exposed group no age effect on prevalence or severity of tooth surface loss Increasing trend by age was observed for unexposed group	Tooth surface loss on the anterior labial and incisal surfaces was more serious	Higher tooth surface loss in exposed compared to unexposed (OR= 11.4) Significant difference in severity of tooth loss in exposed & unexposed ($P<0.001$) Strippers (working in 'cell house') had more severe tooth surface loss compared to other occupations (OR=1.8 for grade 2; & OR=4.59 for grade 3 loss)
Chikte UM 1998[69]	Mineworkers South Africa	Cross-sectional Rapid Epidemiological Assessment (REA)	150 mineworkers were dismissed after a strike (which included complaints due to acidic dental exposure) 58 were back & had complete records after examination (mean age: 37)	Sulfuric acid mists (by-product of electro-plating process)	Questionnaire	Eccles & Jerkins' classification: 0 (no clinical evidence); I (enamel only, loss of labial, lingual, occlusal surface); II (dentin involved in less than 1/3 of the tooth surface lost); III (dentin involved in more than 1/3 of the surface lost)	Photography REA (Rapid Epidemiological Assessment) Clinical records	Chi-square test	Complaints: pain and sensitivity of teeth (for 2/3 of the exposed)	No clear relationship between length of service and dental erosion		Upper incisors were the most severely affected teeth	Prevalence & severity of dental erosion was related with occupation (significant difference between strippers and non-strippers, $p<0.05$)
Dulgergil CT 2007[102]	Turkey, Kirikkale, munitions industry	Case report	Chemical engineer, working in chromium-plate workshop for 20 years Also a heavy smoker, with poor dental hygiene	Chromic acid	Patient history (questions on worksite conditions, eating/drinking habits, other medical conditions, smoking and dental hygiene habits)		Dental examination Patient history Salivary function (stimulated/ un-stimulated)					Tooth wear was apparent on all teeth sites; was significantly high in cervical areas (which have thin enamel)	Severe and extensive dental erosion from chromic acid was reported
Elsbury WB 1951[37]	Tin Factory, UK	Cross-sectional study	15 female workers mixing powders (acid exposed) 16 female workers as controls (unexposed)	Tartaric acid Free tartaric acid (1.1mg/ cm^3)	Gravimetric First lesions of erosion appeared to begin at the 6th month	All levels of dental erosion (from etched surface to dentin exposure and discoloration)	Dental examination		14/15 exposed workers had erosion, vs. none of the controls	Relationship between length of exposure and extent of the dental erosion		Upper incisors	

Study	Study setting / industry / job	Study design	Study Subjects	Exposure (Acid type)	Measuring Exposure	Dental Erosion Classification	Measuring Dental Erosion	Statistical Analysis	% with Dental Erosion (exposed / unexposed)	Dental Erosion / Exposure Duration	Dental Erosion / Age	Dental Erosion / Location	Risk
Fukayo S 1999[103]	Copper-smelter in Japan	Cross sectional study (ABSTRACT in English)	350 male workers	Sulfuric acid		28 had mild dental erosion 20 had opaqueness 11 had concavities 3 had both signs	Blind dental examinations 36% of dental erosion cases & only 14% of non-cases had worked in electrolytic refining plant (significant difference, p< 0.05)		A history of electrolytic refining plant work (acid exposure) increased the prevalence of dental erosion. RR= 3.0 (95% CI: 1.3-6.7) compared to no acid exposure history		Dental erosion was more common in older ages		RR= 3.0 (95% CI: 1.3-6.7) when comparing acid exposed group to non-exposed group
Gamble J 1984[97]	Lead acid batteries manufacture (5 plants)	Cross sectional study	248 workers	Sulfuric acid mist (H_2so_4)	Individual cumulative exposure estimates were calculated Earliest case of etching: 4 months after average exposure of 0.2 mg/ m^3 H_2so_4		Dental examinations	Logistic models Two exposure variables were used 1) cumulative exposure (continuous variable) 2) High/low exposure (categorical variable)		Significant correlation between cumulative acid exposure and years worked (r=0.60)	Significant correlation between age & years worked (r=0.73) also between age & cumulative exposure (r=0.49) No association between age & dental changes (tooth etching & erosion)		Ratio of observed to expected (Ratio O/E) prevalence of etching and erosion was four times greater in the high-acid exposure group
Johansson AK 2005[104]	A truck assembly company, in Sweden (Silicone sealers)	Cross sectional study	13 exposed workers (mean age 30) 10 men, 3 women 20 unexposed workers from the company (age/sex matched), for evaluation of irritative symptoms 13 controls (clinical control group) for dental erosion, age /sex matched, not workers of the company)	Acetic acid vapours	Questionnaire Exposure (acetic acid) level was not measured directly; was estimated based on the duration spent on working with silicon, for each worker	Grade Criteria: · 0 no visible changes · 1 changes on enamel, macro-morphology generally intact · 2 macro-morphology changed, faceting/concavity within the enamel · 3 enamel and macro-morphology changes, < 1/3 dentin surface exposed · 4 enamel changes, > 1/3 dentin surface exposed, pulp visible	Blind clinical examination of the exposed (13), and clinical control group (13) Measuring salivary secretion rate, buffering capacity, visible plaque index, gingival bleeding index, radiographs, study casts, intraoral colour transparencies Erosion index score was obtained-pooled assessments of grading, casts...	Fisher's Exact test-comparison of reported symptoms- exposed & unexposed workers Wilcoxon Signed Ranks test - comparison of dental erosion indices between exposed workers & clinical control group Spearman Rank Correlations (exposure estimates & erosion indices)	The mean erosion index was 1.6 for exposed workers and was 0.92 for the control group (p=0.016)	For exposed group the average time worked was 4.2 years Significant correlation between the period of exposure to silicone & severity of erosion		The mean erosion index was higher for the palatal surfaces	Severity of dental erosion was higher in the exposed group compared to the clinical controls

Study	Study setting / industry / job	Study design	Study Subjects	Exposure (Acid type)	Measuring Exposure	Dental Erosion Classification	Measuring Dental Erosion	Statistical Analysis	% with Dental Erosion (exposed / unexposed)	Dental Erosion / Exposure Duration	Dental Erosion / Age	Dental Erosion / Location	Risk
Kim HD 2003[83]	Factories from plating, galvanizing, chemical, dye, and petroleum industries in Korea	Two sets of case-control studies	242 workers (dental erosion G1-5), 701 workers with no dental erosion 78 workers with severe dental erosion (G3-5) 864 workers with either no erosion or with mild erosion (G0-2)	Sulphuric acid, hydrochloric acid, nitrous acid	Factories were inspected annually based on TLVs for the acidic exposure limits Questionnaire (knowledge on occupational hazards, wearing respiratory masks, gargling during / after work, etc) Personal records of the factories (length of job with acid exposure, etc)	Modified ten Cate's criteria (separate grading for labial/lingual surface, cervical area, incisal area/occlusal surface) · G0 (glossy enamel surface) · G1 (ground glass appearance, white yellowish spot) · G2 (loss of enamel surface or various depression shapes) · G3 (dentinal loss or cupping) · G4 (secondary dentin involved) · G5 (pulp involved)	Clinical examination of teeth (intraexaminer reliability (measured by Kappa index) was 0.9 when 79 workers were reexamined)	Bivariate (chi-square test, or student's t-test) and multivariate logistic regression analysis	Prevalence of overall dental erosion (G1-5) was 25.6% and of severe dental erosion was 8%	In the bivariate analysis workers exposed to acids 3 or more years had a higher prevalence of overall and severe erosion compared to workers with less than 3 years of exposure	Mean age of workers with overall dental erosion was 3.8 years higher than the ones without erosion (G1-5 versus G0) and was 6.4 years higher in severe erosion group (G3-5) than the not severe erosion group (G1-2)		Odds of overall dental erosion (G1-5) 0.63 times less for respiratory mask wearers compared to non-wearers
Kim HD 2006[12]	42 factories using acidic chemicals (ACs), through stratified cluster sampling, Seoul, Korea	Cross-sectional study	519 acid exposed 431 non-exposed	5 types of acidic chemicals (AC) Some were exposed to a combination of ACs; therefore AC exposure was categorized in 9 groups	Questionnaire (length of acid exposure, type of acids, socio-demo-behavioral and occupational factors and systemic factors) All 42 factories studied reported keeping the AC levels under the Korean-TLV recommendations	Modified ten Cate's criteria · G0 (normal) · G1(enamel surface erosion) · G2 (enamel erosion) · G3 (dentin erosion) · G4 (secondary dentin involved) · G5 (pulp involved Severity of dental erosion was categorized in 3 groups (G0, G1-2, G3-5)	3 dentists surveyed exposed and unexposed workers Intra-examiner reliability (Kappa=0.89-0.93); Inter-examiner reliability=0.78-0.86)	Logistic regression analysis to compute Adjusted Odds Ratios (AOR) taking into account confounders & interaction terms Baseline data (smoking/drinking, diet, tooth brushing, GIS disorder) for exposed and unexposed was not significantly different	AOR was: · 1.94 for overall erosion & sulfuric acid exposure · 4 for severe erosion & sulfuric acid exposure · 2.99 for overall erosion & multiple acid exposures (sulfuric, hydrochloric, nitric, chloric) · 14.05 for severe erosion & multiple acid exposures	Length of exposure showed a stronger dose-response relationship with severe dental erosion compared with overall dental erosion (P<0.001) Wearing masks decreased the strength of this relationship			Acidic chemical exposure was associated with erosion severity
Lapping D 1964[38]	A plant manufacturing sanitary cleanser known as 'nitre cake' (Sodium Acid Sulphate), in Johannesburg, South Africa	Case series	20 workers: · 4 (manufacturing of nitre cake) · 1 (operating hammer mill) · 1 (filling of drums from hammer mill, powder) · 14 (filling into a domestic carton)	Sulphuric acid in 'nitre cake' (Sodium Acid Sulphate)			Discovered during a routine dental examination, in the manufacturing plant Together with dental erosion incisoral gingivitis was also present		· 4 workers from the manufacturing of nitre cake had no dental erosions · 1 operating the hammer mill had erosion (1/1) · 1 filling drums from hammer mill had erosion (1/1) · 5 of the workers filling domestic containers had erosion (5/14)	3 months to 10 years exposure duration for all cases		Mouth breathing increased the risk of developing erosion	Risk was higher for workers working around the hammer mill

Study	Study setting / industry / job	Study design	Study Subjects	Exposure (Acid type)	Measuring Exposure	Dental Erosion Classification	Measuring Dental Erosion	Statistical Analysis	% with Dental Erosion (exposed / unexposed)	Dental Erosion / Exposure Duration	Dental Erosion / Age	Dental Erosion / Location	Risk
Malcolm D 1961[41]	Storage battery industry, Manchester UK	Cross-sectional, comparative study	Subjects (exposed and had full teeth): 63 workers from forming & 15 from charging departments Controls: 44 unexposed workers from inspection and packing departments Cases and controls were comparable in terms of age, and social & financial status	Sulphuric acid mist 3.0-16.6 mg/m^3 (on a dry day)	Measurements made on a dry day using "teepol" and ebonite sheets	Tooth Substance Loss classification: · Attrition (loss due to traumatic occlusion) · Etching (no loss) · G1 Erosion (loss of incisal enamel less than 2mm) · G2 Erosion (loss: 0.2- 0.5 of tooth crown) · G3 Erosion (loss more than 0.5 of tooth crown)	Dental examination		In the group with full teeth 57/63 of exposed had attrition, etching or erosion; compared to 11/44 of unexposed (significant difference between exposed/unexposed (p<0.0001), & in unexposed group it was 'attrition', not erosion or etching More workers from forming had erosion & etching compared to the workers from charging (55/63 vs 7/15; p<0.01)	Length of time spent in the department with high exposure had an effect on the severity of lesions Usually, etching started after 3-4 months of work in the department with exposure		Incisor teeth were affected the most (labial surfaces of the centrals and laterals were affected)	Risk of developing attrition, etching or erosion was higher in exposed (workers from forming and charging departments) compared to unexposed group (the difference was significant p<0.0001)
Petersen PE 1991[21]	Modern battery factory, Germany (BRD)	Cross-sectional study	61 dentate workers (mean age: 46)	Sulphuric acid (0.4-4.1 mg/cm^3)	Questionnaire on work environment, dental health, & symptoms from the mouth, nose, and throat	Coding for erosion: · 0 (no erosion), · 1 (enamel loss only), · 2 (dentin involvement), · 3 (secondary dentin exposed), · 4 (pulp exposed)			prevalence of erosion was 31%, of which 92% were also affected by attrition			Erosion was only in front teeth, whereas attrition also occurred in posterior	Due to high level of crown restorations a moderate dose/effect relationship was observed (less than expected)
Remijn B 1982[39]	Hot dip galvanizing plant, The Netherlands	Cross-sectional study (with no comparison group)	Dental erosion was assessed in 38 of 60 production workers (exposed). The rest had dentures or refused to be examined.	Hydrochloric acid	Personal exposure levels were calculated (based on 5 min sampling of the acid exposure) Picklers were exposed to above the MAC-C values of hydrochloric acid 27% of their work time	Bruggen ten Cate's criteria · Etching (dull, ground-glass appearance) · G1(loss of enamel only) · G2 (enamel erosion with also dentin involvement) · G3 (secondary dentin involved)	Examination of colour slides of the teeth of examined workers		89.5% of examined workers had dental erosion (G1 & G2) This figure corresponded with 83% of the examined teeth			90% of workers had dental erosion of the incisor teeth	Prevalence of dental erosion was high; however, there was no control group in this study to make further inferences
Skogedal O 1977[105]	A factory extracting zinc, using electrolytic methods, Norway	Cross-sectional, study (with no comparison group)	12 workers from the electrolysis section (mean age: 34)		Questionnaire on previous occupation, food consumption, oral hygiene habits, medications	Erosion classification · Etching (rough, pitted surface) · G1(loss of enamel only) · G2 (enamel loss with dentin involvement) · G3 (secondary dentin involved) · G4 (pulp involved)	Dental examination Erosion classification, caries classification Radiographs		7/12 exposed workers were affected with erosion of the dental hard tissue	The severity of erosion increased by length of service in electrolysis section About 5-6 years of work was critical for G2 erosion	Correlation between age and attrition was observed; but no association between age and dental erosion was found	Mostly anterior teeth were affected Etching & erosion combined with attrition were seen on posterior teeth	Severity of erosion was related with the length of service

Study	Study setting / industry / job	Study design	Study Subjects	Exposure (Acid type)	Measuring Exposure	Dental Erosion Classification	Measuring Dental Erosion	Statistical Analysis	% with Dental Erosion (exposed / unexposed)	Dental Erosion / Exposure Duration	Dental Erosion / Age	Dental Erosion / Location	Risk
ten Bruggen Cate HJ 1968[3]	Battery factories in Manchester, Glasgow, Wolverhampton, in UK (March 1962-October 1964)	Cross-sectional, comparative study A subset had 4 follow up visits	555 acid workers, 293 controls 324 were examined more than once	Sulphuric, nitric, citric, hydrochloric, hydrofluoric, chromic acids (in various participating factories) Sulphuric & hydrochloric acid accounted for more dental erosion	Questionnaire Occupational acid exposure assessments	· Etching (dull, ground glass appearance) · Grade 1 (Loss of enamel only) · Grade 2 (involvement of dentin) · Grade 3 (exposure of secondary dentin) · Grade 4 (pulpal exposure)	Clinical teeth examination During battery formation galvanizing picklers suffered from erosion more than non-galvanizing picklers Attrition was more prevalent with severe dental erosion		50% of battery formation workers had dental erosion 24.5% of galvanizing picklers 22.3% of non-galvanizing picklers 7.3% of all other occupations	A relationship exists between dental erosion & length of service	No evidence was found that dental erosion was affecting one age group different than the others	Inciso-labial surfaces were worst affected Anterior open bite was observed in some cases Rounded margins were common	Occupation type and length of service were found to be related with dental erosion
Tuominen M 1989[106]	4 factories (2 battery and 2 galvanizing), Finland	Cross-sectional, study	186 workers · 92 acid workers (mean age: 38) · 94 unexposed controls (mean age: 39) 157 dentulous (76 acid, 81 unexposed) workers were analyzed	Sulphuric acid	Sulphuric acid concentration in the air was measured by the Institute of Occupational Health	Erosion was classified based on Eccles and Jerkins' classification: · I (enamel only), · II (less than 1/3 of dentin), · III (more than 1/3 of dentin)	Clinical examinations (some in a university facility, others with mobile dentin unit)	Trend test, chi-square test, rate ratio (RR) were used for the analysis	18.4% of acid workers and 8.6% of controls had one or more teeth with erosion ($p<0.075$)	Longer acid exposure time was significantly related with severity of erosion		Acid workers had erosion on 8% of their upper anterior teeth; controls had 2.6%. ($p<0.01$)	Acid workers had statistically significantly higher teeth erosion compared to the controls (unexposed workers) RR: 2.1 ($P<0.075$)
Tuominen M 1991 (Dental erosion…)[40]	2 battery and 2 galvanizing factories, Finland	Cross-sectional, comparative study	186 workers, of whom 157 were dentate, were analyzed · 76 acid fume-exposed · 81 unexposed (controls)	Almost continuous inorganic acid fume exposure	Questionnaire on previous/ current occupational acid exposure, dietary habits, oral hygiene habits, smoking, medical history	First tried Eccles & Jerkins' dental erosion classification Then, because of the small number of subjects in each group, they used a dichotomous variable with yes (any grade erosion) OR no erosion	Clinical examination of teeth (blinded) Paraffin-stimulated saliva tests (pH, buffering capacity, etc.)	Student's t-test, chi-square test, correlation matrices, logistic regression	12.7% had erosion Inorganic acid exposure was significantly associated with the probability of dental erosion ($p<0.05$) Increased fruit consumption was related with dental erosion ($p<0.04$) No significant association between salivary measures and dental erosion			Anterior teeth with erosion were significantly more numerous than posterior teeth with erosion (4.3% & 1.2%, respectively; $p<0.001$)	Probability of dental erosion increased with acid exposure ($p<0.05$)
Tuominen M 1991 (Tooth surface loss…)[107]	2 factories in Tanzania: Fertilizer factory (inorganic acid fumes) and Sabuni Industry Company	Cross-sectional, comparative study	169 workers from both factories) · 88 exposed · 81 unexposed (controls) Age ~35	Inorganic (sulphuric) acid and organic (sulfonic) acid fumes	Questionnaire	Tooth surface loss graded according to Eccles classification	Clinical examination of teeth (blinded)	Student's t-test, chi-square test were used and OR were computed for all proportional comparisons	On average 23.3% of **inorganic** acid workers' teeth and 13.6 % of controls' teeth had surface loss ($p<0.02$) 19.5% of **organic** acid workers' teeth & 6% of controls' had tooth surface loss ($p<0.05$)	Even by working 1.5 years at the inorganic acid factory, acid-exposed workers had significantly higher tooth surface loss than the control group ($p<0.007$)		Maxillary tooth surface loss was significantly higher in both organic & inorganic acid workers compared to controls ($p<0.02$)	Tooth surface loss was significantly higher in exposed (either inorganic or organic acids) compared to controls. ORs for anterior teeth were the highest

Study	Study setting / industry / job	Study design	Study Subjects	Exposure (Acid type)	Measuring Exposure	Dental Erosion Classification	Measuring Dental Erosion	Statistical Analysis	% with Dental Erosion (exposed / unexposed)	Dental Erosion / Exposure Duration	Dental Erosion / Age	Dental Erosion / Location	Risk
Tuominen M 1992[108]	2 battery & 2 galvanizing factories from Finland, 2 factories from Tanzania (fertilizer and Sabuni)	Cross-sectional, comparative study	Total of 326 dentate workers (Finland and Tanzania) · 164 exposed · 162 controls (unexposed)	Sulphuric acid (battery, galvanizing and fertilizer factories) & sulphonic acid (Sabuni factory)	Questionnaire	Eccles and Jerkins' Tooth surface loss classification: · I (enamel only), · II (less than 1/3 of dentin), · III (more than 1/3 dentin)	Clinical examination of teeth (blinded)	· Chi square and student t-test to examine relation between each factor and tooth surface loss · Regression analysis (Logistic and linear multiple regression)	In Tanzanian group mean number of teeth affected was 8.02 in exposed & 3.93 in unexposed ($p<0.01$)	Length of exposure was strongly correlated with age, therefore not included in final analysis	Age was strongly correlated with length of exposure, significantly associated with tooth surface loss in the Finnish group ($p<0.01$, anterior teeth; $p<0.001$, posterior teeth)	Anterior and posterior teeth both affected. In Tanzanians, effect of acid exposure was more significant on anterior teeth	In Finns older age & less smoking, in Tanzanians longer acidic exposure & less tooth brushing, increased the probability of surface loss in anterior teeth In Tanzanians, exposure was associated with tooth surface loss ($p<0.001$ for anterior teeth and $p<0.05$ for posterior teeth)

Table 2. Wine tasters and dental erosion

Study	Study setting / industry / job	Study design	Study Subjects	Exposure (Acid type)	Measuring Exposure	Dental Erosion Classification	Measuring Dental Erosion	Statistical Analysis	% with Dental Erosion (exposed / unexposed)	Dental Erosion / Exposure Duration	Dental Erosion / Age	Dental Erosion / Location	Risk
Chikte UM 2005[55]	Wine-making industry Tygerberg, South Africa	Cross-sectional, comparative study	36 subjects (21 wine tasters; 15 spouses as controls) Mean age (males exposed): 40.8 Mean age (males non-exposed): 33.3	Not specified. (may be any of the following: malic, lactic, citric, succinic, citramalic acids)	Questionnaire	Tooth surface loss: · Grade 0(no loss), · 1(enamel loss), · 2(less than 1/3 dentin loss), · 3(more than 1/3 dentin loss)	Clinical evaluation of oral cavity	Nonparametric statistical techniques (due to small sample size, distributional difficulties, & high number of ordinal /nominal measurements	Male winemakers (exposed) experienced tooth surface loss 2.5 times more than the male controls (unexposed) When only serious tooth surface loss cases considered, average score in exposed males was double that of controls			In the exposed group, tooth surface loss mostly occurred at labial and incisal surfaces of anterior teeth	Increased severity in the exposed group
Wiktorsson AM 1997[100]	State-owned company on wines and spirits (Vin & Sprit AB) Stockholm	Cross-sectional study	19 qualified wine tasters (7 women and 12 men, aged 29-64 years)	Not specified. (may be any of the following: malic, lactic, citric, succinic, citramalic acids)	Occupational / dental / medical histories	Erosive tooth wear Eccles' classification: · I (enamel only), · II (less than 1/3 of dentin), · III (more than 1/3 of dentin)	Examination of tooth surface loss + photography + measurement of salivary flow rate and buffer capacity (unstimulated & stimulated)	Multiple stepwise regression, correlation, ANOVA, Student t-test for independent samples	14 subjects had tooth erosion; severity varying mild to extreme (also had low unstimulated salivary flow rates) 10.5% had severe erosion	Median length of exposure was 7 years Severity of erosion increased with years of occupational exposure	To compensate for the impact of increasing age, they calculated an exposure index for each subject	Erosion was mainly on the labio-cervical surfaces of maxillary incisors and canines	Increased severity with longer years of occupational exposure

Table 3. Professional swimmers and dental erosion

Study	Study setting / industry / job	Study design	Study Subjects	Exposure (Acid type)	Measuring Exposure	Dental Erosion Classification	Measuring Dental Erosion	Statistical Analysis	% with Dental Erosion (exposed / unexposed)	Dental Erosion / Exposure Duration	Dental Erosion / Age	Dental Erosion / Location	Risk
Centerwall BS 1986[52]	Charlottesville, Virginia	Cross-sectional, comparative study and Case-control study	747 club members 452 swimmers, 295 non-swimmers Subset for case control study: 30 cases from swimmers & 60 controls from non-swimmers (matching age, race, sex)	Gas-chlorinated pool pH was 2.7 as measured by one of the swimmers (HCl is an unwanted by-product of gas chlorination)			Examination of oral cavity by an oral pathologist		Dental enamel erosion reported in 3% (9/295) of non-swimmers, 12% (46/393) of swimmers who were not members of the swim team, and 39% (23/59) of swim team members 30 cases (swimmers) & 60 controls (non-swimmers) were compared (matching age, race, sex) No differences found in terms of occupational, dietary & medical acidic exposures ($p<0.005$) Increased risk of dental erosion for swimmers (OR=4.1 for swimmers and OR=20.3 for members of the swim team			In all 4 case swimmers with clinically evident erosion, enamel erosion was present at the labial surfaces of their teeth	Increased risk (OR) of dental enamel erosion-related symptoms in swimmers

Prevention

An important question is how to prevent dental erosion in the first place. Prophylactic strategies may include decreasing frequency and severity of acid challenge, enhancing defense mechanisms (increasing salivary flow, etc.), facilitating remineralization and hardening of tooth surfaces, weakening abrasive factors, and mechanical protection.[5,109] Once tooth erosion occurs, treatment – likely to include restoration of dentition – could be difficult, extensive, and expensive.[11,110] The location and degree of erosion are important to any treatment plan. The etiologic factor(s) and progression of the condition should be assessed carefully.[111] Johansson states that managing patients' worn dentitions may range from extensive prosthodontics to reliance on adhesive techniques.[112] Sealing of the tooth surfaces and small composite fillings are considered minimally invasive treatments.[113] In any case, continuous monitoring and maintenance will frequently be required. Keeping dated casts of the lesions may help in ongoing care.[23] Early diagnosis and identification of causative factors are important; not only for limiting the cost of treatment and management, but also for increasing the chances for preventing further damage and tooth loss.[11,16,23,114-116] Jaeggi states that "long-term success is only possible when the cause is eliminated".[117]

Isolating one single etiologic factor for any type of tooth wear, including erosion, may be difficult. Tooth wear generally has a multifactorial cause[5,10,23] and even if one factor seems to be predominant, many others will likely occur simultaneously.[9,14] Different mechanisms leading to tooth wear operate either synergistically, sequentially, or alternately.[19] Even if the etiology cannot be specified, a protocol of preventive measures should be initiated immediately after a patient with signs of dental erosion appears at the clinic. In general, early recognition of dental erosion and invoking preventive approaches will limit further damage.[10] Many authors have noted that education and awareness about dental erosion must be increased amongst dentists and the public.[4,62] Patient education should include that various intrinsic factors, such as eating disorder-related vomiting, gastroesophageal reflux due to other diseases, or dry mouth resulting from medications, can be a significant factor in dental erosion. Other possible preventive measures include life style changes to limit the effects of extrinsic acidic exposures. These may involve reducing/eliminating acidic soft drinks or changing consumption habits (using straws, not sipping/swishing/holding drinks in mouth, not having fruit-based drinks or alcohol as a bedtime drink);[10,23,27,118] avoiding toothbrushing before and/or after erosive challenge;[4,9,10,27,65,119] using soft tooth brushes and remineralizing/neutralizing rinses (baking soda solution, milk);[2,27] avoiding low pH dentifrices; or stimulating saliva secretion with sugar-free gums and lozenges.[2,10,27] It has been suggested that fluoride mouth rinses and gels prevent both erosion and caries by boosting remineralization and stimulating salivary secretion.[2,10,120] Attin argues that fluoride also increases resistance to abrasion.[121] Demineralization of enamel is restrained and "physiological balance between hard tissue breakdown and repair is favorably shifted by fluoride".[122] Zero points out that overzealous oral hygiene practices should be avoided.[42] If bruxism is also present, mechanical prevention by an occlusal guard may be appropriate.[10]

In order to prevent dental erosion in industrial settings with high acidic exposure levels, some workplace safety measures can also be considered. Airborne acid levels may have to be constantly monitored and recorded.[48] Erosive effects of these workplace acids may be prevented by exhaust and ventilation systems (lip extraction, roof or wall fans, natural ventilation).[3,48] Use of surface tension reducing agents to prevent fuming and evaporation is also suggested, when appropriate.[3] Malcolm mentions the use of ebonite sheets to cover acid tanks.[41] However, a more effective preventive approach is reducing the accepted threshold limit values of industrial airborne acids to safer degrees that address the risk of dental erosion along with other acid-related occupational diseases.[34,36,83]

For individual care, Malcolm mentions alkaline mouth washes and dentifrice application, which leave a protective film on teeth.[41] Fitted plastic splints/mouthguards for the incisor teeth are also suggested.[14,41]

All dental erosion patients should be monitored over time and their progress should be documented.[10,23] Regular check-ups/screening is suggested for any groups at higher risk for dental erosion.[34,114] Dental erosion should also not be overlooked when promoting dental health.[11]

Coverage policies

There is no specific mention of 'dental erosion' in the WorkSafeBC current policy document. In section 74.30 of the Rehabilitation Services & Claims Manual Volume II it is indicated that "The Board accepts responsibility for dental repair for damage caused by compensable personal injury or occupational disease."

We checked coverage policies in other workers compensation organizations and in private health insurance systems in Canada and in the US. The majority had no structured guidelines or coverage policies for 'dental erosion' posted on their websites. When contacted via email or phone, responses indicated that: claims for dental erosion were scarce (most of the Canadian workers' compensation boards had never had a claim on dental erosion); if any dental erosion claim was received, it would be adjudicated on a case-by-case basis including consultation with an occupational medicine physician and/or dentist (some workers' compensation boards mentioned that their specialized adjudication team would deal with this type of claim); and the entitlement decision would take into account the current board/company policies, circumstances of employment (duration of exposure, protective equipment available at the workplace, etc.), and medical evidence. In any case, "arising out of and in the course of employment" was stated as the apparent single, basic policy to be used to adjudicate the claim. (Popp S. (Workers' Compensation Board Alberta) email, June 19, 2009)(Davies D. (Saskatchewan Workers' Compensation Board) email, June 22, 2009)(Vanderbyl S. (Yukon Workers' Compensation

Health and Safety Board) email, June 25, 2009)(Stacey N. (Workers' Compensation Board of Nova Scotia) email, June 26, 2009)(Hood SJ. (Workers Compensation Board of PEI) email, June 30, 2009)

We also contacted the UK Industrial Injuries Advisory Council (IIAC) to find out their policies in place for dental erosion. IIAC reviews their occupational coverage decisions on various occupational diseases and publishes an annual report. They stated that currently, the erosion of teeth was not prescribed as an industrial injury, and that the policy had not been reviewed since the original report, which was published in October 1966. (Hegarty C. (IIAC) email, March 9, 2009)[123]

Take home messages

I- Overall evidence suggests that normal levels, but not pathological-levels, of tooth erosion/wear is age dependant.[86,110,124] However, at least one study argues that pathological wear is also age dependant,[125] and some studies do not distinguish between pathological or normal tooth wear when studying the effect of 'age' on tooth erosion.[60,126]

II- Once dental erosion emerges, some signs that can point to active (current/ongoing) and/or rapidly progressing erosion include shiny/smooth tooth surfaces with no staining, development of hypersensitivity, and restorations sticking-up amongst the dissolving teeth.[2,14,23] In some cases, hypersensitivity might be delayed by accumulation of tertiary dentin.[28] Generally, there is a synergy between dental erosion and dental hypersensitivity.[27]

III- Working in certain occupations/industries increases the risk of acidic exposure and dental erosion. Airborne acid environments are found in mineral, battery, chemical, tin, dyestuff, and fertilizer industries, as well as metal industries engaging in galvanizing, plating, silicone sealing, and acid pickling.[3] Laboratory workers (pipetting by mouth), wine tasters,[42] and professional swimmers also face higher acid exposures.[51,53-55]

IV- Studies on dental erosion due to industrial airborne acidic exposures found that:

1. Most of the time, dental erosion occurs at the labial surface of anterior teeth.[3,21,34-41,48,69,106]
2. Compared to central and lateral anterior teeth, canines are less affected.[3,41,48]
3. Usually, the line separating eroded and normal enamel coincides with the lip-line, indicating that the areas uncovered by the lips/cheeks are at higher exposure risk.[38,41]
4. Prevalence of dental erosion is higher in workers in battery and galvanizing occupations.[34] For example, battery workers, exposed to sulfuric acid, have the highest prevalence (60%) of erosion, with 20% being severe cases.[3]
5. Some studies point out a significant correlation between the duration of acidic exposure (length of service) and the severity of erosion.[3,21,34,41,48,105,106]

V- Studies on dental erosion due to non-industrial acidic exposures found that:
   1. Dietary and/or gastric acid exposures commonly affect the palatal surfaces of upper incisors, canines and premolars.[30]
   2. Chances of developing lingual erosion – especially in a more serious form – are higher in the case of gastric acid exposures compared to dietary exposures.[30]
   3. Most of the time, cervical surfaces of teeth are affected, usually with shiny/smooth, disc-shaped, shallow cavities.[41]

VI- Interplaying factors can be important in determining the level of acidic exposures:
   1. Occupational environment (accepted threshold values for airborne acids, ventilation systems, availability of personal protective equipment, etc.)
   2. Cultural practices, educational level, living area, and dietary choices (bed-time drinks, vegetarian diet, increased juice/pop consumption in a hot climate, etc.)
   3. Personal hygiene habits (type of toothpaste and mouth washes, fluoride use, toothbrushing habits, etc.)
   4. Salivary composition (pH, calcium and phosphorus content, flow rate, etc.)
   5. Systemic diseases/medications (eating disorders, gastroesophageal reflux, hydrochloric acid or Vitamin C supplements, etc.)

Conclusion

Dental erosion is a multi-factorial process. Several extrinsic (e.g. occupational exposures, foods and drinks, medications, alcohol, gas-chlorinated swimming pools) and intrinsic (e.g. gastroesophageal reflux, regurgitation, vomiting due to eating disorders, pregnancy, and alcoholism) sources of acids may be contributing simultaneously or consecutively. There are also modifying factors, such as salivary composition (e.g. pH, calcium and phosphorus content, flow rate and buffering capacity), oral hygiene (e.g. toothpaste type, toothbrushing habits, fluoride rinse, and other dentifrice use) and eating/drinking habits (e.g. using a straw, not having alcohol and/or acidic fruits/juices before bedtime).

When dental erosion is diagnosed, contributing factors (either etiologic or modifying) should be identified as soon as possible. Rigorous history taking (medical and life style) and a thorough oral examination should be performed. Photography, study casts, and tooth wear indexes should be used as diagnostic tools. Contributing factors should be weighed based on duration, intensity, and sequence of exposure(s). When a workplace (or other environmental) exposure is suspected, a workplace exposure assessment should be undertaken. A workplace survey may help capture new cases with early stage dental erosion. A company's compliance with the allowable Threshold Limit Values (TLVs) for the potential hazardous acid material(s) should be investigated. However, it should be borne in mind that dental erosion can also develop even below the required TLVs. During etiologic assessment, decisions based solely on the location of the erosive lesions should be avoided.

The evidence from epidemiologic studies on occupational dental erosion is limited. This review by the Evidence-Based Practice Group (EBPG) of WorkSafeBC found that most of the studies are either case reports/case series or cross-sectional studies (quality of evidence level 4 or 5). They usually point out the prevalence of tooth surface loss/erosion in a certain occupational setting. Some of these studies have comparison groups (unexposed controls) and some report Risk Ratios or Odds Ratios, based on acid exposure level (different occupational groups with different proximities to acid source), length of exposure (working duration/years), or severity of the lesions (dental erosion classifications). Studies have used various exposure measurement techniques and clinical dental erosion classifications, and this makes comparisons of the results impossible. Most of the time, data on modifying factors (workplace preventive measures, personal dental hygiene, dietary habits, etc.) are either not collected or not controlled for during the analysis. Usually, studies have small sample sizes and are conducted in specific occupational settings. Therefore, the results are not generalizable to other populations. As it would be unethical to allocate study subjects to acid exposures, randomized controlled trials with human subjects are lacking, and systematic reviews are mostly narrative. Some in vitro studies are also available.

Determining the main contributing factor(s) in dental erosion is complicated. Given the weak evidence from the literature, when dealing with an occupational dental erosion claim, decisions should likely be made on an individual case by case basis. The EBPG of WorkSafeBC recommends that the "arising out of and in the course of employment" rule to be an appropriate basis of any assessment when concluding on "occupational hazard(s)" as the main contributing factor(s) of dental erosion. Management, treatment, and compensation decisions should follow accordingly.

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Appendix 1

WorkSafeBC Evidence-Based Practice Group levels of evidence adapted from [1,2,3,4]

1	Evidence from at least 1 properly randomized controlled trial (RCT) or systematic review of RCTs.
2	Evidence from well-designed controlled trials without randomization or systematic reviews of observational studies.
3	Evidence from well-designed cohort or case-control analytic studies, preferably from more than 1 centre or research group.
4	Evidence from comparisons between times or places with or without the intervention. Dramatic results in uncontrolled experiments could also be included here.
5	Opinions of respected authorities, based on clinical experience, descriptive studies or reports of expert committees.

References

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