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PHYSICAL, CHEMICAL, CLINICAL AND BIOLOGIC ASPECTS OF THE ACID ETCH BONDING TECHNIQUE IN ORTHODONTICS*

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Summary

Acid etch bonding is an accepted and reliable technique widely employed in orthodontic mechanotherapy. In this paper some of the physical and chemical aspects associated with the bonding of orthodontic attachments to human dental enamel are discussed. It highlights some of the intra-oral factors affecting adhesion. The principles of the acid etch technique, the effect of acid etching upon normal human enamel and some biologic aspects of the technique are discussed. Remineralization, decalcification and caries associated with the technique are considered as well as other possible damage to the dental and surrounding tissues.

An understanding of the processes of the acid etch bonding technique will permit its better employment in orthodontic mechanotherapy and secure a permanent place for this method of treatment.

Introduction

Dental researchers have sought to develop materials that will consistently maintain adhesion to tooth structure in the oral environment. Swartz (1969) stated that none of the materials available to the dental profession up to that time could consistently maintain adhesion under intraoral conditions. A brief resume of some of the problems encountered in the oral environment will permit a better understanding of the reasons for the development of the acid etch technique in dentistry. Certain problems peculiar to this technique will be discussed and an attempt made to answer some questions posed by the profession and the public.

Physical and Chemical Aspects

Adhesion is defined as the attraction exerted between the surfaces of bodies in contact or the attraction between molecules at an interface (Buonocore, 1963). This force is called adhesion when unlike molecules are attracted and cohesion when molecules of the same kind are attracted.

Adhesion is dependent on intimate interfacial contact and smoothness at an atomic level. It is impossible to obtain such atomically smooth surfaces and if rough surfaces are brought together, the molecular forces of attraction will operate only where the tips of the asperities of the surfaces meet. These are so widely spaced that the attractive forces are small and poor adhesion will result. In order to obtain adhesion between rough surfaces, adhesives are introduced between the surfaces and their function is to adapt to the irregularities of the surfaces to be bonded thereby establishing close contact with them. This molecular closeness once established must be maintained and thus a liquid adhesive that solidifies is necessary. The liquid

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adhesive, in order to produce adequate adhesion, must flow easily over the entire surface thus ensuring "wetting" of the adherend surface.

The extent to which an adhesive will "wet" a surface depends on the viscosity of the adhesive, the shape of the irregularities on the surface of the adherend, and the contact angle at which the adhesive meets the surface of the adherend. Zisman (1963) pointed out that the larger the contact angle the more imcomplete will be the wetting and this will result in weaker adhesive bonds.

Glantz (1969) suggested that enamel surfaces are covered with a low energy organic film which prevents the proper wetting of the enamel surfaces by the adhesive. It is therefore extremely difficult to attain adhesion to low energy tooth surfaces. Furthermore, adhesion is best obtained and maintained under dry conditions and in the oral cavity this is a problem. Beebe (1961) showed that even if a vacuum pump were applied to the mouth, a patient's tooth could not be thoroughly dried at room temperature. Even if it were possible to dry a tooth surface completely, the dryness could not be maintained because of fluid flow which occurs from the pulp of a tooth to the enamel surface (Bergman 1963). The adhesive must thus compete with water for binding sites on the tooth surface. The presence of water in the oral environment may be the precursor of chemical activity at the adhesive/adherend interface which will eventually dislodge the bond. Adhesive materials may absorb water leading to swelling and dimensional changes in their bulk resulting in stress concentrations at the interface which will have an adverse effect on the bond strength.

The carboxylate cements were developed by Smith in 1968. Since no dental cements were capable of achieving true adhesion to human enamel, the carboxylates were of greater interest. These cements were shown to have the ability to chelate to calcium ions of the dental enamel thus achieving chemical bonding. Sadowsky (1974) on evaluating certain orthodontic cements under laboratory conditions found that the carboxylate cement tested exhibited poor cohesive properties which resulted in failure within the cement itself during force application. This finding corroborated a similar observation of Phillips (1973). He concluded that the strength of the carboxylate cement to enamel exceeded the linear tensile strength of the cement. It is noted that chemical union does occur between some commercially available bonding cements and some plastic brackets.

It was primarily due to the lack of truly adhesive dental materials that the acid etch technique was developed. Buonocore (1955) showed that by etching or conditioning enamel surfaces with phosphoric acid the bond strength of dental materials to enamel could be substantially increased. The effect of etching of enamel is to remove the organic cuticle from the enamel surface and thus produce a high energy surface over which the adhesive will readily spread resulting in intimate interfacial contact (Fig. 1). In addition, the preferential etching action of the acid produces micropores in the enamel surface into which the setting cement will flow and results in mechanical retention of the cement. This ensures the formation of strong bonding between the cement and etched enamel.

Clinical Aspects:

Research and development has reached the stage where orthodontic brackets and attachments can be successfully and predictably bonded to etched enamel (Fig. 2).

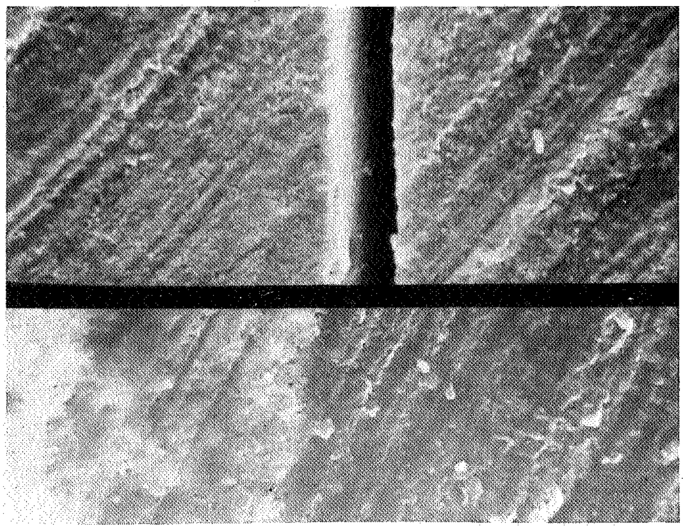

Fig. 1. Poor interfacial contact between the enamel (left) and a bonding cement (right) in the upper scanning electron micrograph. In the lower micrograph intimate interfacial contact has been established as a result of prior acid etching of the enamel (left). (SEM X2000).

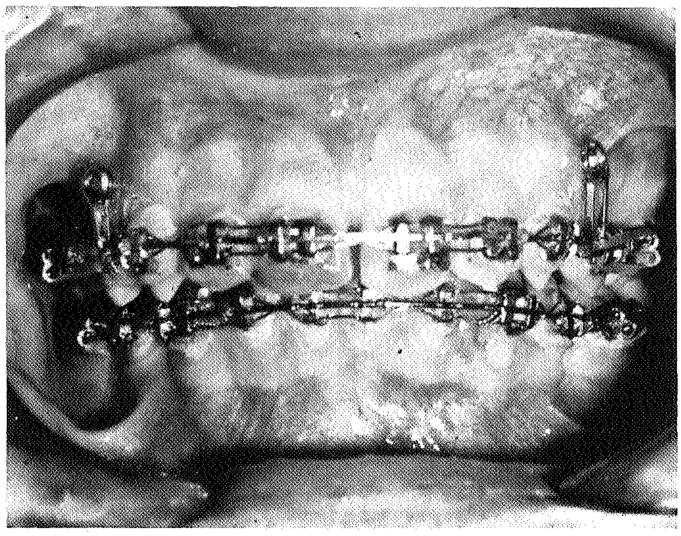

Fig. 2. Directly bonded orthodontic brackets with archwires in place.

Numerous bonding materials have become commercially available and many techniques have been described for the clinical placement of the orthodontic attachments. The basic premise, however, of orthodontic bonding or indirect bonding is the prior acid etching of the dental enamel. Laboratory and clinical evaluation of the materials and methods have been carried out, including tensile bond strength tests, solubility tests and scanning electron microcopic studies in addition to clinical evaluation of some of the materials. Many of the materials satisfactorily meet the criteria required for the purpose for which they were intended. Improvements have also been made in the orthodontic brackets specifically manufactured for use with this technique.

Some years ago a pilot clinical evaluation of a direct bonding system was undertaken. This utilized an epoxy resin formulation developed by Retief, et.al. (1967). At that time no commercially available brackets were available. In order to obtain retention of the bonding material to the brackets a metal gauze backing was welded onto the back of orthodontic brackets. The clinical pilot study involved etching of the enamel with a 50% phosphoric acid solution and bonding the brackets to the etched enamel with the epoxy resin formulation. Eight patients were treated in the preliminary clinical trial and fifty eight teeth were bonded. The duration of treatment time ranged from 3 to 48 months and the number of bonded attachments per patient ranged from 1 to 15. During the treatment of these patients 14 bonded attachments became dislodged and the failure rate was calculated as 24% (Retief and Sadowsky 1975).

Although the bonding process employed at that time may by today's standards be considered rather crude, we were encouraged to proceed with a more definitive clinical study after certain modifications were introduced as a result of experience obtained during the pilot study.

In the definitive clinical study 15 patients were treated and 123 attachments were bonded. The duration of the treatment ranged from 5 to 35 months and 23 attachments became dislodged. A failure rate of 18.8% was recorded. The above-mentioned clinical studies extended over a 7 year period.

Recently several materials for the bonding of orthodontic attachments have become commercially available and laboratory studies have proven excellent bond strengths of these materials to etched enamel surfaces under simulated intra-oral conditions. Proof of the success of the bonding systems is evidenced by the number of orthodontists today employing the direct or indirect bonding systems in their offices. Among the advantages cited for the use of bonding are: decreased gingival irritation, no banding space required, utilization in patients with partially erupted teeth, no final space closure necessary, decreased decalcification of enamel and caries formation, ease of placement and so forth. Bonding has without doubt become an invaluable adjunct in the armamentarium of the orthodontist.

In order to ensure success with any technique adherence to certain requirements is advisable. Aids to ensure high success rates with the technique of your choice will include prevention of excess adhesive flowing beneath bracket flanges by protecting the flanges with Alastic or similar materials; adequate retraction of the soft tissues; avoiding topical fluoride application on the enamel prior to bonding; adequate measures to ensure a dry field of operation; and well trained assistants.

Under controlled conditions the bonding technique has proven to be invaluable in modern orthodontics and most orthodontists will bond at least some brackets in their offices. As with all techniques the preference of the operator will determine the extent to which bonding is employed.

Biologic Aspects

Because of the widespread use of acid etch bonding in orthodontics, it is desirable to consider biological aspects of this technique since it has introduced certain problems peculiar to it.

When normal enamel is etched with phosphoric acid, which is the most common conditioning solution, the smooth glistening clinical surface is replaced by a dull white opaque appearance. When enamel is examined by means of the scanning electron microscope, reasons for its altered clinical appearance become manifest. The scanning electron microscope is eminently suited to study surface enamel topography since its depth of focus enables visualization in three dimensions. Sound normal human enamel has a relatively featureless appearance (Fig. 3) whereas

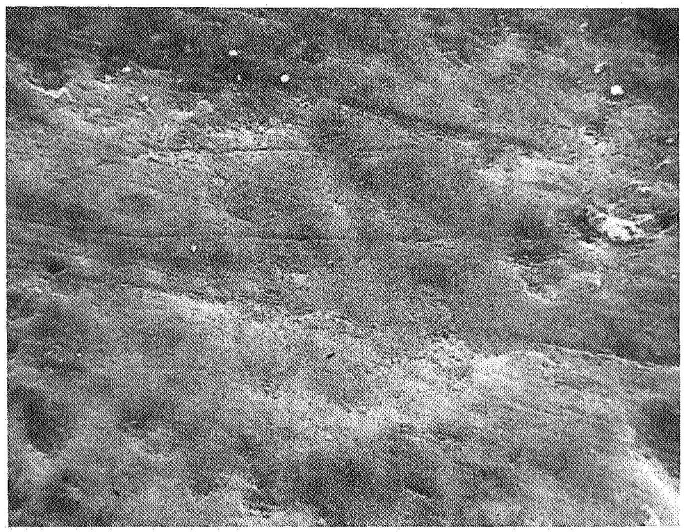

Fig. 3. Featureless appearance of sound normal human enamel (SEM X2000).

etched enamel is roughened due to loss of enamel material. This results in a typical honey-comb appearance or prism-end structure due to the preferential etching action of the enamel cores by the acid. The etching pattern is however variable (Fig. 4). Scanning electron micrographs from adjacent areas of the same tooth will demonstrate this observation. In some areas the prism peripheries are etched to a greater extent than the prism cores. In other areas a mixed etching pattern is evident resulting from preferential etching of prism peripheries. Areas of prismless enamel may also be noted (Fig. 4). It has been shown that deciduous teeth have a greater abundance of "prismless" enamel and hence bonding strengths to decisuous teeth will not be as great as to permanent teeth. The etching pattern is also dependent on the enamel prism orientation.

Conditioning of enamel surfaces with acidic etching solutions has caused concern because of the possible permanent damage to tooth surfaces. In view of this we studied the in vivo recovery of etched enamel surfaces. The buccal surface of a maxillary premolar which was etched with phosphoric acid for one minute showed preferential etching of the prism peripheries. This tooth was extracted soon after etching for orthodontic reasons. The contra-lateral tooth was extracted 2 weeks after etching and showed apparent recovery of the etched surface. The smoother

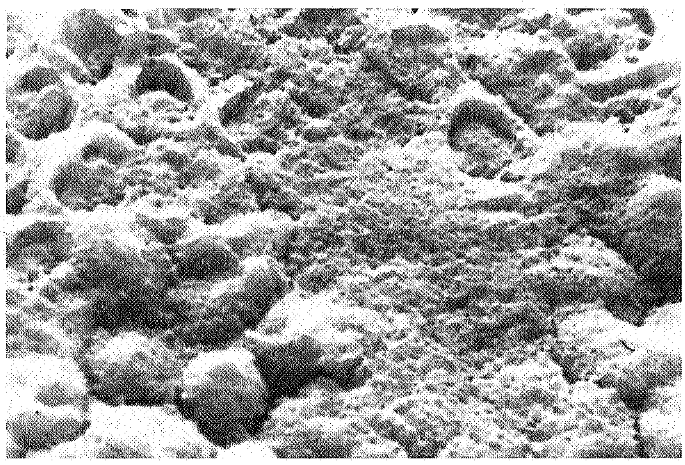

Fig. 4. Variable enamel etching pattern. Lower left of micrograph shows preferential etching of enamel periphery while upper areas reveal preferential etching of enamel cores. The central band reveals mainly prismless enamel (SEM X2000).

appearance could be due to the deposit of salivary glycoproteins, to abrasion or erosion of the etched enamel surface or remineralization of the conditioned enamel within the oral cavity. Wei and Sierck (1971) and Lee and his coworkers (1972) have shown by means of sophisticated analytical methods that complete recovery by remineralization of etched surfaces occurred after exposure to the oral environment after a few weeks.

Electron microscope studies have shown that etched enamel surface appearance can be restored to a more normal enamel appearance by pumice polishing. A brief polishing period resulted in a smoother surface appearance while an etched surface which was polished for a longer period closely resembled sound unetched human enamel (Fig. 5).

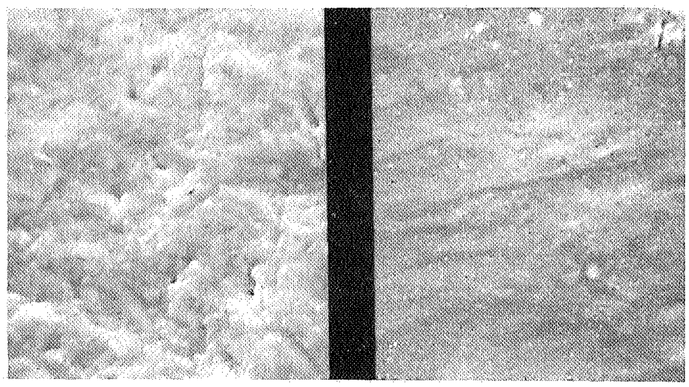

Fig. 5. Scanning electron micrograph of etched enamel that was subsequently polished with pumice. The left side was polished minimally while the appearance on the right shows the effect of a longer polishing period (SEM X2000).

It has been shown by Retief (1975) by means of surface profile recordings that the depth of etch, or the amount of surface enamel removed by 50% phosphoric acid applied for one minute is of the order of 7 micrometers.

Since acids are employed to etch the enamel it is essential that great care be taken to prevent excess acid coming into contact with the gingival tissues. Phosophoric acid can cause sloughing, severe irritation and even focal necrosis of the periodontal tissues. Furthermore, after the period of acid etching, it is mandatory to wash away all acid on the teeth and employ adequate suction.

Etching of enamel produces intimate interfacial contact of the enamel with the bonding material. The micropores in the enamel produced by the acid etching, will allow penetration of the enamel by fine filamentous tags of bonding material and this will explain the resulting intimate interfacial contact (Fig. 1). These penetrative tags, as previously mentioned, allow for the retention of the resin of the etched enamel surfaces by mechanical interlocking. Retief (1973) has shown that the filamentous tags may extend up to 50 micrometers in length into etched enamel.

Solubility and disintegration tests were carried out on some composite materials currently being used for bonding and under laboratory conditions these proved to be insoluble over the 24 hour test period. Direct extrapolation of these findings to the intra-oral environment should be tempered with caution but when compared to other cements used for band cementation the composites at least proved to be superior over the test period (Sadowsky and Retief, 1976). The latter conclusion was reached after testing marginal leakage by means of a fluorescent dye technique adapted from that used by Holliger (1967).

An obvious advantage in using dental adhesives or cements which are insoluble is the probability of a reduction in microleakage at the cement/enamel interface since an ingress of bacteria and salivary components occurring at this interface could predispose to enamel decalcification and dental caries. Routine oral hygiene procedures must be strictly adhered to. The importance of the cement/enamel interface in band cementation, as described by Sadowsky and Retief (1976), is equally applicable in the bonding situation where an adequate seal could prevent or minimize deleterious effects beneath the bonded attachments. Furthermore, the acid etching of enamel will permit the bonding cement to fill micropores within the enamel and this enamel has been shown to be more resistant to further acid attack. Gwinnett and Matsui (1967) have observed that material which had penetrated into the enamel provided continued protection of the enamel crystals by encapsulation of these crystals.

When bonded attachments are employed excess bonding material should be removed. The effect of excess cement on oral hygiene and on the surrounding gingival tissues are only too well known.

Let us now consider the re-bonding of a detached orthodontic bracket. If the enamel surface is scaled and polished and then re-etched, a very roughened surface appearance is observed under the scanning electron microscope (Fig. 6). The etching pattern is greatly altered due to remnants of bonding material remaining encapsulated within the enamel (Sadowsky and Retief, 1976). Re-bonding will occur since micropores are still created and furthermore the newly applied bonding resin will probably also chemically bond with the material previously encapsulated within the enamel. A clinical impression is that the retention of an initially bonded attachment was better than that of a re-bonded attachment.

At the completion of treatment the bonded attachments were removed. Immediate-

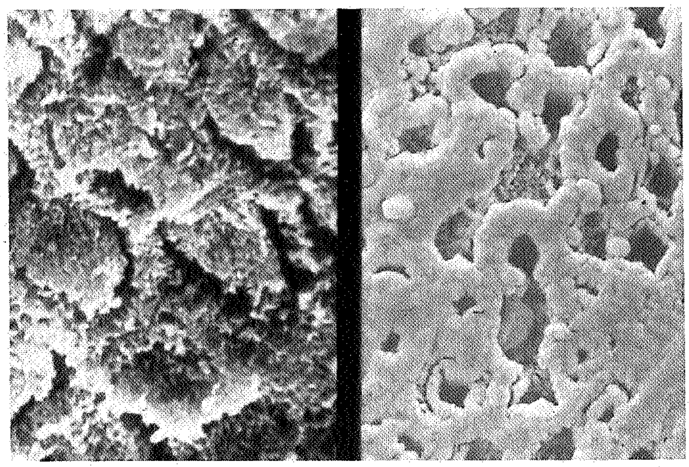

Fig. 6. Scanning electron micrograph of enamel etched with 50 percent solution of phosphoric acid for one minute (left). The appearance after a bonded attachment was removed, the surface cleaned and polished and then re-etched with 50 percent solution of phosphoric acid. (SEM X2000).

ly after removal a dull enamel appearance with fragments of projecting resin is clinically evident. Scanning electron microscope studies have shown that remnants of bonding resin are not completely removed by scaling with hand instruments alone and a very rough surface results (Sadowsky and Retief, 1976). We thus require additional mechanical polishing. Inadequate pumice polishing still leaves a rough enamel surface which could promote debris accumulation, whereas adequate polishing produced an acceptable surface profile (Fig. 7). This enamel surface will

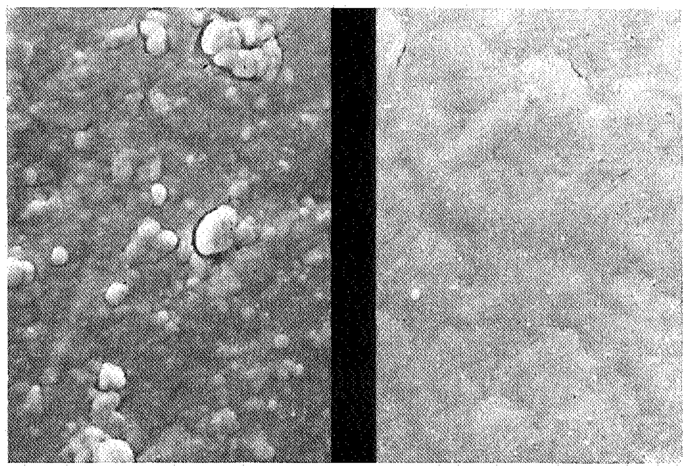

Fig. 7. Scanning electron micrographs of enamel surfaces which had bonded attachments removed and the surfaces scaled and polished. The right side shows the effect of more adequate polishing when compared with the left side which was polished for a shorter period. (SEM X2000).

still have bonding material embedded within it and, as previously stated, the remaining material which had penetrated into the enamel will provide prolonged protection of the enamel crystals to acid attack. The clinical appearance after adequate polishing of the bonded enamel surface was most satisfactory.

During the laboratory evaluation of the tensile bond strengths of resin systems to etched enamel, it was observed that fractures within the enamel occurred in some of the specimens. It is noteworthy that the tensile bond strengths of composite materials approximate, and sometimes exceed, the linear tensile strength of human enamel. This could easily result in fractures occurring within the enamel and fragments of enamel being pulled out during the removal of bonded attachments. Great care must therefore be exercised when bonds are removed and the surfaces subsequently well polished after removal of these attachments. It is considered that newer materials with increased tensile bond strengths are not necessary, perhaps even contra-indicated. We observed fractured enamel under laboratory conditions where tooth dryness could be well controlled. The fact that intra-orally teeth cannot be completely dried, due to fluid flow from the pulp to the enamel surface, should usually minimize this occurrence due to the probability of decreased bond strengths. However, a note of caution is sounded when we consider direct bonding onto devitalized root filled teeth since these are more brittle than vital teeth and where hardly any fluid flow occurs from the interior of the tooth onto the enamel surface.

Not infrequently young patients who require orthodontic treatment present with fractured teeth, and when dentine is exposed, problems associated with the acid etch technique could arise (Fig. 8). When phosphoric acid is applied to freshly exposed dentine, the result experimentally was displacement of the odonblast nuclei into the dentinal tubules. This phenomenon was observed in experimental monkeys three days after application of 50% phosophoric acid for one minute onto exposed dentine. After 14 days micro-abcess formation was often observed while after six

Fig. 8. Fractured incisor tooth. Care must be exercised to avoid acid etching agents from coming into contact with exposed dentine.

weeks a layer of reparative dentine had formed in specimens examined (Retief et.al. 1974). Although these results were observed in experimental animals, it is highly likely that a similar sequence of events would occur in man. It is therefore suggested that exposed dentine should be protected when acid etching adjacent enamel.

Conclusion

The acid etch bonding technique is an invaluable adjunct in the armamentarium of the orthodontist. It is considered that continued investigation into all aspects of this technique is desirable in order to gain a better understanding of the effects of procedures we employ during treatment of our patients.

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