CHAPTER II

LITERATURE REVIEW

The literature review is divided into five parts as follows:

I. Dental fluorosis

II. Conventional phosphoric acid adhesive systems

III. Etching pattern

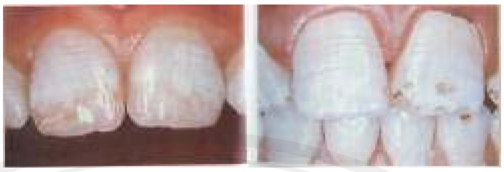
IV. Effect of fluorosis on bond strength

V. Adhesive resin cement

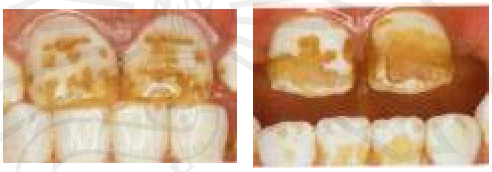
I. Dental fluorosis

Dental fluorosis is a specific disturbance of tooth formation caused by excess fluoride intake.[10] It can occur either as an acute or chronic exposure during tooth formation. Its characteristics include retention of amelogenins in the early maturation stage and formation of porous enamel in the subsurface layer.[1] Dental fluorosis has various forms, such as fine white lines across the entire tooth surface, small, white, opaque areas, brownish discolorations,[2] or pitted enamel. Teeth exhibiting severe forms of dental fluorosis are prone to fracture and wear (Figure 2.1).[1]

a) Mild form



b) Moderate form



c) Severe form

Figure 2.1. Types of severity of dental fluorosis : a) Mild form b) Moderate form c) Severe form.[11]

The severity of dental fluorosis depends on many factors, such as the amount of fluoride ingested, the duration of exposure, individual susceptibility and the stage of amelogenesis at the time of exposure.[1,2]

Normal enamel is the most highly mineralized tissue known, consisting of 96% mineral and 4% organic material and water. The inorganic content of enamel is a crystalline calcium phosphate, hydroxyapatite, which is also found in bone, calcified cartilage, dentin and cementum (Figure 2.2). Various ions such as strontium, magnesium, lead and fluoride, if present during enamel formation, may be incorporated into or absorbed by hydroxyapatite crystals.

Figure 2.2 Electron micrograph of enamel crystals. The organic material and water of enamel exists in the spaces between the crystals.[12]

Enamel is essentially a tightly-packed mass of hydroxyapatite crystals. Indeed, the basic structural unit of enamel, the rod, owes its existence to a highly organized pattern of crystal orientation. The rod is shaped somewhat like a cylinder and is made of crystals whose long axes run, for the most part, parallel to the longitudinal axis of the rod (Figure 2.3).[12]

Figure 2.3 Scanning electron micrograph of partially demineralized enamel. Enamel rods run from left to right.[12]

In fluorosed enamel, the protein content is greater than that of normal enamel. Normal enamel protein content ranges from 0.07% to 0.14%, while fluorosed enamel protein content ranges from 0.03% to 0.56%.[13] However, the amino acid profiles are similar for fluorosed and normal enamel.[14] Fluorosed enamel has also been shown to have an increased magnesium content.[1]

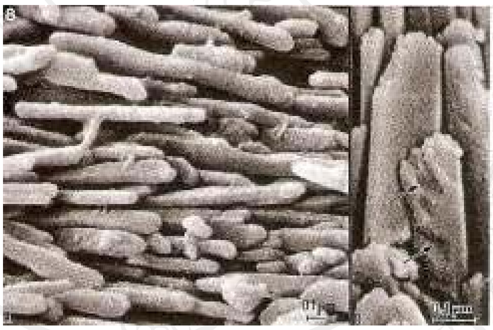
Fluorosed enamel is characterized by an outer hypermineralized, acid-resistant layer, and by the formation of more porous enamel in the area of the subsurface hypomineralization. The highly-mineralized enamel surface layer is composed of a mixture of many large and extremely small crystals; irregularly shaped crystals are observed (Figure 2.4). Seen in cross-section, the large crystals have flattened hexagonal shapes (Figure 2.5).

Figure 2.4 Scanning electron micrograph obtained from the highly mineralized surface layer of enamel. A number of large crystals and many extremely small, irregularly shaped crystals are observed.[15]

Figure 2.5 Transmission electron micrograph of cross-cut crystals obtained from the highly mineralized surface layer. Large flattened hexagonal crystals are scattered throughout the section, and many extremely small, irregularly-shaped crystals can be observed among them.[15]

Small crystals are usually distributed among the large crystals, and occasionally they appear to be attached to each other. Though of various shapes, they have a basically hexagonal configuration. The rims of hexagonal crystals may be either equal or unequal. The small crystals usually have diameters less than half those of the large crystals.

The hypomineralized enamel area is composed of fairly sparsely arranged, large crystals and a few small crystals (Figure 2.6A). Dissolution from the surfaces may be observed in some crystals, which exhibit irregularly shaped defects (Figure 2.6B).



(A) (B)

Figure 2.6 Scanning electron micrographs obtained from the hypomineralized areas. Picture "A" shows many large crystals arranged rather sparsely. A few small crystals are observed among these large crystals. Picture "B" shows irregular defects (arrows) formed on the surface of a crystal.[15]

In cross-section, the flattened hexagonal crystals are generally smaller than those observed in the surface layer. In some parts of this area the crystals have large perforations in their centers.[15]

Subsurface hypomineralization is accompanied by a higher proportion of protein than normal.[10,13] This layer contains a porous part (Figure 2.7) and as the degree of dental fluorosis increases the degree of subsurface porosity increases. If pore volume in the subsurface layer is more than 10-15 %, fracture of enamel can result.[16] The main feature of fluorotic enamel is an outer hypermineralized and acid-resistant layer, which is difficult to bond because a reliably etched enamel surface cannot be produced.[1]

(A) (B) (C)

Figure 2.7 shows the porous part of fluorosis. (A) Section from permanent first molar with severe dental fluorosis. (B) Loss of surface enamel is seen corresponding to the location of the most porous part of the subsurface lesion. (C) Higher magnification subsurface lesion from an area where outer surface is maintained.[16]

The risk of dental fluorosis depends on the dose of fluoride relative to body weight. For upper central incisors the risk is greatest for children between the ages of 15 and 30 months. When the first permanent molars erupt at about 6 years, the coronal parts of the anterior teeth are nearly complete, and ingestion of fluoride at this age will have little effect on the development of the anterior teeth. In older children, the risk of dental fluorosis moves to the posterior teeth.[2] Dental fluorosis is more severe in posterior teeth than in anterior teeth, in both maxilla and mandible.[17] Whereas the maxillary molars and premolars are more affected on the palatal surface, the mandibular teeth appear more severely affected on the buccal surface.[16]

The first report of what was probably dental fluorosis was made by Kuhn[18] in 1888, who described teeth of persons in areas of Mexico that were opaque, discoloured and disfigured. Data in the United States of America, suggest that in areas with fluoride addition in the water supply, 8-51% of children develop dental fluorosis, whereas in areas with no fluoride addition only 3-26% of children develop dental fluorosis.[19] In the north of Thailand the water has a high natural level of fluoride.[20] The provinces of northern Thailand with high fluoride levels are: Chiang Rai, Chiang Mai, Phayao, Mae Hong Sorn, Lampang, Lampoon, Tak, Sukothai, Chainat, Phichit and Phetchburi. National dental health surveys in 1994 found that dental fluorosis in 12-year-old children in Northern Thailand was 17%.[6] The percentages of dental fluorosis in the northern provinces of Thailand are: Chiang Rai 45.6%, Chiang Mai 50%, Phayao 32.6%, Mae Hong Sorn 53.7%, Lampang 59.8%, Lampoon 30.3 %, Tak 41.1%, Sukhothai 4.4%, Chai Nat 14.2%, Phichit 28.4% and Phetchburi 47.4%.[6]

In 1942, Dean[21] established an index for measuring dental fluorosis. The index is shown in Table 2.1.

Table 2.1 show Dean's fluorosis index.[21]

Classification	Criteria
Normal (0)	The enamel represents the usual translucent semivitriform type of structure. The surface is smooth, glossy, and usually of a pale, creamy white color.
Questionable (0.5)	The enamel discloses slight aberrations from the translucency of normal enamel, ranging from a few white flecks to occasional white spots. This classification is used in those instances where a definite diagnosis of the mildest form of fluorosis is not warranted and a classification of "normal" not justified
Very mild (1)	Small, opaque, paper-white areas scattered irregularly over the tooth but not involving as much as approximately 25% of the tooth surface. Frequently included in this classification are teeth showing no more than about 1-2 mm of white opacity at the tip of the summit of the cusps of the bicuspids or second molars

Classification	Criteria
Mild(2)	The white opaque areas in the enamel of the teeth are more extensive, but do not involve as much as 50% of the tooth
Moderate(3)	All enamel surfaces of the teeth are affected, and surfaces subject to attrition show wear. Brown stain is frequently a disfiguring feature
Severe(4)	All enamel surfaces are affected and hypoplasia is so marked that the general form of the tooth may be affected. The major diagnostic sign of this classification is discrete or confluent pitting. Brown stains are widespread and teeth often present a corroded appearance.

But this index has many limitations, such as difficulty of classification into various categories in the milder forms, lack of clarity, imprecision and lack of sensitivity.[22,23] In 1987, Thylstrup and Fejerskov established a new classification system for dental fluorosis, called the TF index (after the authors' names) shown in Table 2.2 and Figure 2.8.[11,16] This index is more precise, sensitive and easier to use than Dean's index.[22]

Table 2.2 Thylstrup and Fejerskov's fluorosis index.[11]

Classification	Criteria
TF score 0	The normal translucency of the glossy, creamy-white enamel remains after wiping and drying of the surface
TF score 1	Thin, white, opaque lines are seen running across the tooth surface. Such lines are found on all parts of the surface. The lines correspond to the position of the perikymata. In some cases, a slight "snow-capping" of cusps/incisal edges may also be seen.
TF score 2	The opaque, white lines are more pronounced and frequently merge to form small cloudy areas scattered over the whole surface. "Snow-capping" of incisal edges and cusp tips is common.
TF score 3	Merging of white lines occurs, and cloudy areas of opacity occur spread over many parts of the surface. In between the cloudy areas white lines can also be seen.
TF score 4	The entire surface exhibits a marked opacity, or appears chalky white. Parts of the surface exposed to attrition or wear may appear to be less affected.
TF score 5	The entire surface is opaque, and there are round pits (focal loss of the outermost enamel) that are less than 2 mm in diameter.

Classification	Criteria
TF score 6	The small pits may frequently be seen merging in the opaque enamel to form bands that are less than 2 mm. in vertical height. In this class are included surfaces where the cuspal rim of facial enamel has been chipped off , and the vertical dimension of the resulting damage is less than 2 mm.
TF score 7	There is a loss of the outermost enamel in irregular areas, and less than half the surface is so involved. The remaining intact enamel is opaque.
TF score 8	The loss of the outermost enamel involves more than half the enamel. The remaining intact enamel is opaque.
TF score 9	The loss of the major part of the outer enamel results in a change of the anatomical shape of the surface/tooth. A cervical rim of opaque enamel is often noted.

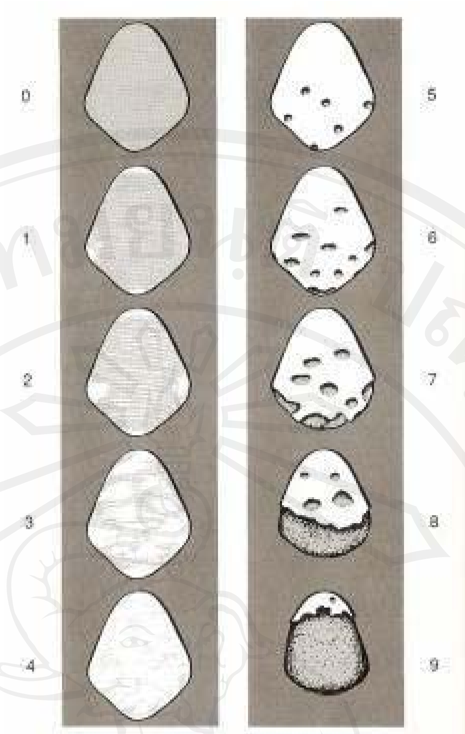


Figure 2.8 Diagrammatic illustration of the clinical features of dental fluorosis from its mildest form (TF score 1) to the most severe (TF score 9).[11]

II. Conventional phosphoric acid adhesive systems

Since Buonocore[24] introduced the acid etch bonding technique in 1955, others have developed applications of the concept of bonding various resins to enamel in all field of dentistry, including the bonding of orthodontic brackets.[25,26] In 1965, the use of acid etch techniques in the direct bonding of orthodontic attachments was first reported by Newman.[27] The process involves etching the enamel surface with phosphoric acid to increase porosity and enhance retention. This approach has several advantages, e.g., enhanced ability for tooth cleaning, including plaque removal, by the patient, minimized soft-tissue irritation and hyperplastic gingivitis, elimination of the need for separation of teeth for banding, absence of post-treatment band spaces, facilitation of application of attachments to partially erupted teeth, minimized danger of decalcification with loose bands, easier detection and treatment of caries, and a more esthetic appearance.[28]

Buonocore[24] found that acrylic resin could be bonded to human enamel that was conditioned with 85% phosphoric acid for 30 seconds. Today, etch-and-rinse procedures involves the use of phosphoric acid with a concentration between 30% and 40% and an etching time of not less than 15 seconds. Washing times of 5 to 10 seconds are recommended to achieve the most receptive enamel surface for bonding.

Historically, controversy existed about the concentration of phosphoric acid that would provide optimal etching efficacy, because some acids might form precipitates on the surface that might interfere with resin bonding. One study showed that 50 % phosphoric acid applied for 60 seconds on enamel produces a precipitate of monocalcium phosphate monohydrate that can be rinsed off.[29]

A precipitate of dicalcium phosphate dihydrate produced by etching with a less than 27% phosphoric acid was found not to be easily removed.[29] Calcium dissolution and etching depth increase as the concentration of phosphoric acid increases until the concentration reaches 40%. Although most commercial etchants have concentrations between 30% and 40%, lower concentrations may be used without compromising enamel bond strength.

The etching time has also been reduced from the traditional 60-second application with 30% to 40% phosphoric acid to etching times as brief as 15 seconds.[29] Several laboratory clinical studies have demonstrated equivalent bonding effectiveness with etching times from 15 to 60 seconds.

Adequate rinsing is an essential step. Phosphoric-acid-etched enamel must be rinsed thoroughly (five seconds per tooth etched with liquid, ten seconds per tooth etched with gel) and dried before the application of the bonding resin.[30]

Adhesion to enamel is achieved through acid etching of this highly mineralized substrate, which substantially enlarges its surface area for bonding.[29] Further research into the underlying mechanism of the bond suggested that tag-like resin extensions were formed and microporosities created by etching.

Acid etching removes about 10 µm of the enamel surface and creates a microporous layer from 5 to 50 µm deep. Three enamel-etching patterns have been described. These include Type I, in which there is predominant dissolution of the prism cores; Type II, in which there is predominant dissolution of the prism peripheries; and Type III, in which the pattern of the enamel surface is irregular, no prism structures are evident.[29]

Bonding success or failure begins with the tooth surface.[30] The proper conditioning of the surface of the tooth, whether it is enamel, composite, porcelain or metal, is a variable that must be controlled when bonding a bracket with adhesive. A surface that is not conditioned properly or one that becomes contaminated cannot produce satisfactory bond strength regardless of adhesive type.

Orthodontic appliances are bonded with chemical ("no-mix" and "two paste mix"), light- or dual-cure systems that can be equally successful if their inherent variables are controlled. System™ 1+ (Ormco) and Unite™ (3M Unitek) are chemical cure "no mix" adhesive systems. The "no mix" system has two components: a single liquid primer (catalyst) and a single paste. The primer is applied to the etched, dried enamel and the bracket base. The paste then is applied to the bracket base and the bracket is placed on the tooth. The primer serves as the catalyst for the paste. Even though it is termed "no mix" this system actually mixes the paste and primer directly on the tooth. Therefore, to mix the paste and primer properly and achieve maximum strength, the bracket base must fit the tooth surface flush. A thin, as opposed to a thick, coat of primer must be applied to the enamel and the bracket base. The primed/pasted bracket is placed on the tooth and pressed to place when in the desired position.[30] To summarize, the variables with a “no mix” system are:

1) Bracket base must fit the tooth surface flush.

2) Thin coat of primer on tooth surface.

3) Thin coat of primer on the bracket base.

4) Thin layer of paste on the bracket base.

Willems *et al*[31] tested 22 commercially used orthodontic adhesives and three types of bracket adhesives: chemical-cured, light-cured, dual-cured. They found that among “nomix” adhesives, Unite™ produced the highest bond strength.

III. Etching pattern

III. Etching pattern

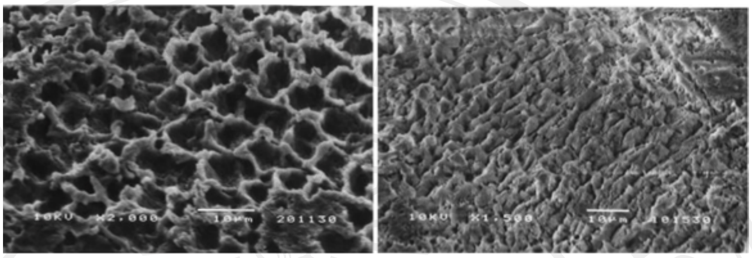
Direct bonding of orthodontic attachments can be used successfully as a routine clinical procedure.[32] Direct bonding is a method that is easy, fast and inexpensive. The bonding technique depends on the mechanical locking of adhesive to irregularities in the enamel surface of the tooth and to mechanical locks formed in the base of the orthodontic attachment. However, there are three components to orthodontic bonding: preparation of the tooth surface, preparation of the surface of attachment and bonding materials.[32]

Generally, enamel etching produces three different micromorphologic types of surface, which can be seen with scanning electron microscopy (SEM).[12] The most common is Type I (Figure 2.9A), characterized by preferential removal of the rod core. In the reverse, Type II, the rod periphery is removed and the core remains intact (Figure 2.9B). Occurring less frequently is Type III, in which the pattern of the enamel surface is irregular (Figure2.9C).

(A) (B) (C)

Figure 2.9 Scanning electron micrographs of etching patterns in enamel. A, Type I pattern, rod core preferentially eroded; B, Type II pattern, rod boundary preferentially eroded; C, Type III pattern, indiscriminate erosion.[12]

Fluorotic teeth have the highest concentration of fluoride in the outer 200 µm of enamel. The concentration of fluoride in this region increases with increasing TF score.[33] The hypermineralized surface layer of fluorotic enamel is difficult to etch, resulting in less irregularity of the enamel surface than in normal enamel.[8,34,35] Al-Sugair *et al.* found that fluorosed enamel showed typical Types I, II and III etching patterns which were independent of the severity of fluorosis. When TF score increased, the etching pattern tended to be less accentuated (Figure 2.10).[35]



(A) (B)

Figure 2.10 Scanning electron microscope photomicrograph showing: (A) Type I etching pattern on enamel specimen at TF score =1 etched for 30 seconds; (B) rather indistinct etching pattern of enamel specimen at TF score = 5 etched for 30 seconds.[35]

Those findings are consistent with those of Shida *et al.*, who reported that the fluorosed enamel surface has an etching pattern different from that of normal enamel. The fluorosed enamel surface also has an efficacy lower than that of the non-fluorosed enamel surface when use self-etching primer (Figure 2.11).[36]

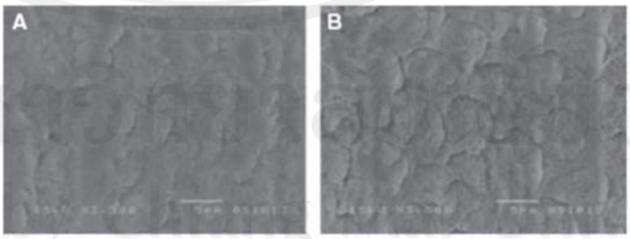


Fig 2.11 Scanning electron microscopy (SEM) images of enamel surfaces treated with Clearfil SE bond primer for 20 seconds. (A) Fluorosed enamel surfaces. (B) Non-fluorosed enamel surfaces. The etching effect on the fluorosed enamel surface appeared to be less than that on the non-fluorosed enamel surface.[36]

The depth of etch for the fluorosed enamel tends to increase with etching time at TF scores 0-3.[35] On the other hand, depth of etch fluctuates at TF scores of 4 and 6. However, the etching patterns become more accentuated with increased etching time. So, Al-Sugair and Akpata recommended an etching time of at least 30 seconds for fluorotic teeth with TF =4 and at least 90 seconds for more severely fluorotic teeth.

IV. Effect of fluorosis on bond strength

Successful orthodontic treatment depends on an adequate bond strength of orthodontic bracket to enamel. It has been suggested that sufficient bond strength for clinical orthodontic bonding is between 6 to 8 MPa.[37] Ng'ang'a *et al*.[38] found no statistically significant difference between the mean values for bond strength of orthodontic brackets in fluorosed and non-fluorosed teeth. They bonded brackets with a composite resin after over-etching the enamel surface with 40% phosphoric acid for 60 seconds. The result of their study revealed that fluorosed teeth decreased the bond strength compared with non-fluorosed teeth, however, the difference was not statistically significant. These finding are consistent with those of Ateyah and Akapata,[39] who reported that the degree of fluorosis had no significant effect on shear bond strength of composite resin to enamel. However, Miller, reporting on the difficulty of bonding to fluorotic teeth, found that bond failure of fluorotic enamel occurred mostly at the enamel-composite interface.[7] Another report of shear bond strength of fluorotic teeth found that routine acid etching showed less than sufficient bond strength for clinical orthodontic bonding.[40] These findings are consistent with those of Adanir *et al.*, who reported that fluorotic teeth significantly decreased the bond strength of orthodontic brackets.[41,42]

VI. Adhesive resin cement

Resin cements based on methyl methacrylate have been available since 1952 for cementation of inlays, crowns and appliances. Resin cements were evaluated for direct bonding for orthodontic brackets (without bands) in the late 1960s. Advances in acid etching of enamel substantially increased the popularity of the technique in the mid-1970s. Resin cements are used with metal, plastic or ceramic orthodontic brackets. Resin cements can be classified as autopolymerization, or self cured, photoacivated, or light cured, or dual activated, or dual cured, resin cements.[43]

Superbond C&B is a self-cured adhesive resin cement. It has the ability to chemically bond to tooth structure, metal and porcelain.[44,45] This resin cement can be used for permanent cementation of all cast restorations, including crowns, inlays, posts and Maryland Bridges.[44] Besides, Superbond C&B has been widely used for bonding orthodontic brackets and provides a strong bond.[46-48] The main ingredients of Superbond C&B are monomer, polymer, and Catalyst S. The main composition of the polymer is polymethyl-methacrylate (PMMA), which is polymerized MMA (methyl-methacrylate). 4-methacryloxyethyl trimellitate anhydride (4-META) is added to the monomer to promote diffusion. Tri-*n*-Butyl borane (TBB), the main composition of Catalyst S, is an initiator for polymerization.[46] Tight bonding of orthodontic brackets to enamel is produced by 65% by weight phosphoric acid etching.[48] 4-META is a di-functional monomer displaying both hydrophobic methacrylate and hydrophilic aromatic anhydride components (Figure 2.12). The hydrophobic methacrylate component is able to mix with resins in composite/acrylic adhesive, while the hydrophilic aromatic anhydride component is able to promote adhesion to the tooth surface and to provide higher bond strength and better stability after the polymerization.[49,50] Because Superbond C&B contains no inorganic filler, bracket removal is easy and there is low risk of enamel fracture.[51]

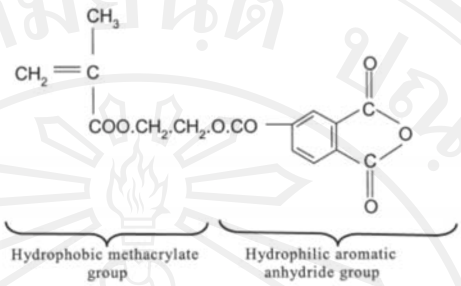


Figure 2.12 Molecular structure of the 4-META monomer[49]