Original Article

An *in vitro* comparison of shear bond strength using different bonding techniques in amelogenesis imperfecta cases

ABSTRACT

Introduction: The objective of this study is to assess and compare shear bond strength (SBS) using different bonding techniques in amelogenesis imperfecta (AI) cases.

Materials and Methods: Totally 30 extracted premolars from AI cases and 10 premolars from normal cases were obtained. The first group of (10) normal samples was treated with 37% orthophosphoric acid (H_3PO_4), second group (10) of AI cases was treated with conventional technique (37% H_3PO_4), third group (10) with sodium hypochlorite (5% NaOCl), and fourth group (10) with 2% sodium fluoride (2% NaF). Brackets were bonded using Transbond XT light curing adhesive and SBS was measured using the Instron universal testing machine.

Results: Statistically highly significant difference observed between the strengths of all four groups ($P < 0.01$) with the mean highest for control group followed by NaF conditioning and NaOCl conditioning and least for conventional bonding procedure in AI cases. On pairwise comparison using Tukey's *post hoc* test, statistically highly significant difference was observed between the mean SBS for control group versus Group 2, Group 3, and Group 4, Group 2 versus Group 3, and Group 2 versus Group 4.

Conclusion: Brackets bonded by conventional technique showed lower SBS as compared to NaOCl and NaF in AI cases. The application of 2% NaF gel for 4 min before acid etching of hypomineralized tooth surface shows significantly higher SBS as compared to conventional and NaOCl group in AI cases.

Keywords: Amelogenesis imperfecta, shear bond strength, sodium fluoride, sodium hypochlorite

INTRODUCTION

The success or failure of an orthodontic treatment can be greatly determined by the bonding of orthodontic attachments. The principle of bonding attachments to the enamel is based on micromechanical interlocking of the adhesive resin with the enamel. High failure rates of resin bonding using the current conventional technique are reported in amelogenesis imperfecta (AI) cases wherein the enamel is reduced or may even be completely absent. This study has given us an insight into different bonding techniques in such cases which might bring down the failure rates associated with bonding and thus the cost associated with maintenance.

Bonding of orthodontic attachments using orthodontic adhesives is one of the important procedures in orthodontic practice. Enamel is the outermost layer of the crown which does not have the capacity to regenerate or repair. It is composed predominantly of inorganic structure, making up

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to 96% by weight and the remaining 4% by organic structure and plasma.[1,2]

The fundamental principle of bonding to dental hard tissues is based on micromechanical interlocking of the adhesive resin with the enamel and dentin.[3]

While bonding to enamel depends on the micromechanical retention to the etched substrate,[4] bonding to dentin relies on hybridization with the exposed collagen mesh.[5]

A significant number of patients seeking orthodontic treatment have local or generalized hypomineralized areas in one or more teeth due to hereditary or environmental factors. Enamel hypomineralization may be a result of incipient caries or may be due to a systemic condition known as molar incisor hypomineralization.[6]

AI is a heterogeneous group of hereditary disorders that may affect the enamel of some or all teeth in the primary and/or permanent dentition.

AI has been reported as an isolated finding with an autosomal dominant, autosomal recessive, or X-linked mode of inheritance.[7,8]

Incidence

The estimated frequency of AI in the population varies between 1:718 and 1:14.000 in the western population. AI affects 1 of 14,000–16,000 children in the United States.[9]

Witkop (1957) classified AI based primarily on the phenotype.[9] Five types were as follows:

1. Hypoplastic
2. Hypocalcification
3. Hypomaturation
4. Pigmented hypomaturation
5. Local hypoplasia.

The diagnosis of AI frequently presents with sensitive and discolored teeth. Poor dental esthetics is the result of surface roughness, staining, and abnormal crown shapes from enamel loss. Clinical management is considered to improve the poor appearance and function of the affected teeth using bonded restorations.[10]

Clinical presentation of AI varies according to its type. In the hypomaturation type, the affected teeth exhibit mottled, opaque white-brown yellow-discolored enamel, which is softer than normal. In radiographs, the thickness of enamel is normal, but its density is the same as that of the dentin. The hypocalcified type shows pigmented, softened, and easily detachable enamel. Radiographically, enamel thickness is normal, but its density is even less than that of the dentin. In the hypoplastic type, the enamel is well mineralized, but its amount is reduced. Clinically, grooves and pits will be realized on the surface of the fine enamel. The rough pattern of hypoplastic type exhibits thin-, hard-, and rough-surfaced enamel. The tooth is tapered toward the incisal/occlusal face and has open contact points. Radiographs exhibit a thin peripheral outline of radiodense enamel and low or absent cusps.[7,11] Clinical and radiographic appearances of the teeth of our cases were harmonious with hypomaturation-type AI.

In this study, diagnosis of hypomaturation-type AI is based on the family history, clinical observation, and meticulous recording which form the backbone of diagnosis.

In this study, two chemical solutions (sodium hypochlorite [NaOCl] and sodium fluoride [NaF]) were used to improve bond strength in AI cases.

Mechanism of action of sodium hypochlo rite

- According to De-Deus *et al.*, NaOCl eliminates the organic matter present on the enamel surface by dissolving it.
- When enamel is deproteinized with NaOCl, more Types 1 and 2 patterns of conditioning were found, while without NaOCl, more Type 3 patterns were found. According to Silverstone *et al.* (1975), the more retentive etching patterns are Types 1 and 2 because the porous surface offers more retentive areas of greater size and depth.
- NaOCl as a deproteinizing agent is a possible strategy to optimize adhesion by removing organic elements of the enamel structure before acid etching.
- NaOCl has an antibacterial effect. Its mechanism of action has been explained by Solera and Silva-Herzog.[12]
    - pH similar to calcium hydroxide ($CaOH_2$)
    - NaOCl + HO → NaOH (sodium hydroxide) + HClO (hypochlorous acid). NaOH acts on fatty acids forming soap (saponification), which reduces surface tension. The HClO etches and neutralizes amino acids
    - The chlorine ion acts on cell metabolism inhibiting its enzymatic action
    - The hydroxyl ion binds to calcium ions denaturalizing protein formation of $CaOH_2$.

Mechanism of action of sodium fluoride

The mechanism of action of fluoride gel is considered to result from its local action on the tooth plaque interface through promoting remineralization and by reducing tooth enamel solubility.[13]

Enamel demineralization is markedly inhibited if fluoride is present at the time of acid challenge because fluoride diffuses with the acid from plaque into the enamel and acts at the crystal surface to reduce mineral loss. When pH rises following demineralization, fluoride can combine with dissolved calcium and phosphate ions to precipitate or grow fluorapatite-like crystalline material within the tooth. Fluoride enhances this mineral gain and provides a material that is more resistant to subsequent acid attack.[14]

Schmidlin *et al*. reported that fluoride-treated, acid-etched demineralized enamel allowed good penetration of a bonding agent. The low microleakage scores observed in the hypomineralized/NaF group may be related to adequate resin adhesion and high bond strength. The precipitation of calcium fluoride (CaF_2) on the surface of NaF-treated hypomineralized enamel may have a great inhibitory effect on microleakage.[15,16]

Hicks and Silverstone reported that fluoride treatment followed by acid etching of demineralized enamel produced the highest shear bond strength (SBS) in teeth with demineralized enamel. Previous studies found that fluoride treatment followed by acid etching of caries-like lesions provided etching patterns that were suitable for adhesive placement, while creating a rapid supply of fluoride for remineralization that reharden the enamel.[17] The same has been reported by Shahabi *et al.* who found that application of 2% NaF before acid etching of demineralized enamel caused a significant increase in bond strength of orthodontic brackets.

It has also been demonstrated that fluoride treatment followed by acid etching of hypomineralized enamel can produce etching patterns similar to those observed in etched sound enamel, while restoring the mineral lost during lesion formation.[17]

The essence of adhesion depends on achieving the best acid etching, with a generalized retentive morphological condition over the enamel and the dentine surface. High failure rate of resin bonding using the current conventional technique is reported in AI cases wherein the enamel is reduced resulting in hypersensitivity (Ohsawa, 1972; Van Meerbeek *et al*., 2001).

Topical fluoride is especially important in such AI patients because of their high risk of caries and it may also reduce hypersensitivity to a significant extent and improve this effect when associated with the occlusion of the dentin tubules.[18]

Studies by Rada and Hasiakos, Seow, and Saroğlu *et al*. have reported high failure rates in resin-dentin bonding to AI-affected teeth.[19-21]

Frequent bracket debonding in AI or hypomineralized cases is a common shortcoming in clinical orthodontics and might delay treatment completion and increase the costs relative to the maintenance of fixed orthodontic appliances.

Hence, the purpose of this study is to assess and compare SBS using different bonding techniques in AI cases.

MATERIALS AND METHODS

1. Extracted teeth: Total 40
    - 30 extracted premolar teeth from AI cases (hypomaturation type) and 10 extracted premolar teeth from normal cases stored in distilled water [Figure 1a and b].
2. Solutions used [Figure 2]
    - 5% NaOCl
    - 2% NaF
    - Distilled water
3. Bonding kit – 37% phosphoric acid, Transbond XT primer, Transbond XT adhesive, applicator tip, and light-emitting diode (LED) [Figure 3].
4. Universal testing machine (UTM) [Figure 4].

Methods

Sample unit

A sample of 30 extracted premolar teeth from hypomaturation-type AI cases and 10 extracted premolar teeth from normal cases who were undergoing orthodontic treatment.

Allocation

The groups were divided as follows: Group I (10 teeth): Control. And 30 teeth were randomly and equally allocated into the following three groups:

- Group II (10): Conventional bonding procedure
- Group III (10): NaOCl conditioning
- Group IV (10): NaF conditioning.

37% orthophosphoric acid was applied to the tooth surface and left for a period of 15 s. The tooth was then washed and air-dried until a dull frosty appearance was seen. The procedure was done for all the test specimens to be bonded with three different bonding techniques to be evaluated.

Group 1 (control): Teeth surfaces were etched with a 37% phosphoric acid gel for 15 s. The tooth was rinsed with a copious amount of water and dried with an oil-free air spray. Then, a thin coat of Transbond XT primer (3M Unitek) was applied on the surface and the bracket was placed in the center of the crown with the use of Transbond XT adhesive (3MUnitek).

Figure 1: (a) Extracted premolars of normal cases. (b) Extracted premolars of amelogenesis imperfecta cases

Figure 3: Bonding kit

The excess composite was removed from the periphery of the base with a dental explorer and the bracket was light cured for 40 s from occlusal, gingival, mesial, and distal directions using Bluephase LED as shown in Figure 5.

Group 2 (conventional): The bonding procedure was the same as the control group (Group 1), but brackets were bonded on hypomineralized enamel (hypomaturation AI) as shown in Figure 6.

Group 3 (NaOCl): Teeth surfaces were etched with a 37% orthophosphoric gel (H_3PO_4) for 15 s, then rinsed with copious amount of water, and dried with an oil-free air spray. A 5% NaOCl solution was applied on the enamel surface for 1 min, then rinsed with water, and air-dried. Again, teeth surfaces were etched with a 37% phosphoric acid gel for 15 s. The tooth was rinsed with a copious amount of water and dried with an oil-free air spray. Then, a thin coat of Transbond XT primer was applied on the surface and the bracket was placed on crown with the use of Transbond XT adhesive and then light cured with Bluephase LED as shown in Figure 7.

Group 4 (NaF): In this group, a 2% neutral NaF gel was applied on the enamel surface for 4 min. Subsequently, the teeth were rinsed with water for two consecutive periods of 5 min each after application of NaF for 4 min to remove any readily

Figure 2: Chemical solutions

Figure 4: Universal testing machine (Instron)

soluble reaction products, which if not removed can interfere with etching process affecting bond strength. Then, the teeth were etched with 37% phosphoric acid gel, then rinsed with water, and air-dried. Then, a thin coat of Transbond XT primer was applied on the surface and the bracket was placed on center of crown with the use of Transbond XT adhesive and then light cured with Bluephase LED as shown in Figure 8.

All the bonded teeth were kept in distilled water at 37°C for 24 h and then mounted in dental stone so that the buccal surface of the tooth was parallel to the direction of the debonding force [Figure 9].

Evaluation of bond strength

SBS was measured using the Instron UTM. A parallel knife edge shearing device was aligned 0.05 mm from the bonded interface and force was applied to cause debonding using a crosshead speed of 1 mm/min. The stress value was recorded [Figure 10].

RESULTS

Table 1 explains the numerical values of the SBS of the ten

Figure 5: Bonding procedure by conventional technique in normal cases

Figure 7: Bonding procedure by 5% sodium hypochlorite conditioning in amelogenesis imperfecta

samples examined in each group. Lowest SBS was recorded in Group 2 at 5.02 MPa and the highest in Group 1 at 13.78 MPa.

Statistical analysis

Data obtained were compiled on a MS Office Excel Sheet (v 2010). Data were subject to statistical analysis using the Statistical Package for the Social Sciences (SPSS v 21.0, IBM, Armonk, New York, The United States of America).

Intergroup comparison of mean SBS (between the groups) was done using one-way ANOVA followed by pairwise comparison using *post hoc* Tukey's test.

For all the statistical tests, $P < 0.05$ was considered to be statistically significant, keeping α error at 5% and β error at 20%, thus giving a power to the study as 80%.

Table 2 describes the mean SBS of the four groups with the respective standard deviation. The lowest mean SBS was recorded in Group 2 at 5.48 and the highest in Group 1 at 11.505 followed by Group 4 at 7.651and Group 3 at 6.659.

Figure 6: Bonding procedure by conventional technique in amelogenesis imperfecta

Figure 8: Bonding procedure by sodium fluoride conditioning in amelogenesis imperfecta

Table 3 presents the results of the *post hoc* test wherein each group's mean SBS has been compared with the mean of the other three groups.

There was a statistically highly significant difference between the strengths between the following pairs

- Control versus Group 2, Group 3, and Group 4
- Group 2 versus Group 3, Group 2 versus Group 4.

However, there was a nonsignificant difference between Group 3 and Group 4 ($P > 0.05$).

Inference

MPa values are statistically similar/not different for Group 3 and Group 4.

Table 4 describes the results of the one-way ANOVA test between the four groups and within the groups. The difference between the four groups was found to be statistically significant.

There was a statistically highly significant difference between the strengths of all four groups ($P < 0.01$) with the mean highest for control group followed by NaF conditioning and NaOCl conditioning and least for conventional bonding procedure.

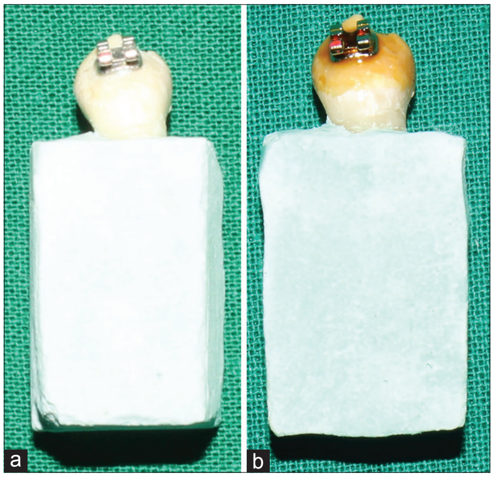


Figure 9: (a) Bonded normal tooth mounted on dental stone. (b) Bonded amelogenesis imperfecta tooth mounted on dental stone

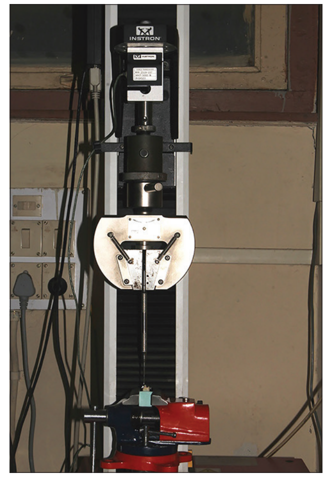


Figure 10: Shear bond strength test using universal testing machine

Table 1: Shear bond strength values

Number of samples	Shear bond strength (MPa)			
	Group 1 (control)	Group 2 (conventional)	Group 3 (NaOCl)	Group 4 (NaF)
1	10.21	5.24	6.28	8.89
2	12.00	6.00	7.12	6.20
3	10.09	5.02	7.24	7.29
4	10.44	5.19	7.14	7.68
5	13.34	5.81	6.20	8.34
6	12.67	5.16	6.12	7.22
7	10.22	5.08	7.16	7.09
8	11.87	6.03	6.22	8.24
9	10.43	5.09	7.02	7.32
10	13.78	6.18	6.09	8.24

NaOCl: Sodium hypochlorite, NaF: Sodium fluoride

Table 2: Overall descriptives of numerical data

Groups	*n*	Mean	SD	SE
Control	10	11.505	1.410	0.445
Conventional bonding procedure	10	5.480	0.464	0.146
NaOCl conditioning	10	6.659	0.5081	0.160
NaF conditioning	10	7.651	0.785	0.248
Total	40	7.823	2.439	0.385

SD: Standard deviation, SE: Standard error, NaOCl: Sodium hypochlorite, NaF: Sodium fluoride

Graph 1 presents graphical interpretation of mean SBS values of the four groups with the Group 1 (control group) showing highest SBS at 11.505 followed by Group 4, Group 3, and Group 2 in decreasing order of bond strength.

DISCUSSION

Major concern associated with AI cases is altered quality and quantity of enamel, which can make the attachment and retention of fixed brace problematic. The chemical composition and mechanical properties also vary with the extent of hypomineralization, which influences the bonding performances.[22]

Hiraishi *et al*. in their study showed that bonding could not be improved by increasing etching time in AI cases. Keeping this finding in mind, the etching time was kept similar in all three groups.[10]

A reduction in mineral content and an increase in protein content pose great challenges to bonding to teeth with AI using adhesive restorative materials.

The action of H_3PO_4 on the enamel occurs mostly on the mineralized tissue (inorganic matter). Moreover, H_3PO_4 does not eliminate the organic matter. In AI cases, outer organic layer prevents the conventional 37% H_3PO_4 from effectively etching the surface resulting in inconsistent pattern and an unreliable enamel surface for bonding. Thus, it is necessary to remove the organic matter from the enamel surface to enhance the quality of etching pattern, which gave rise to the concept of deproteinization.

Venezie *et al*. reported in their study that pretreating enamel affected by AI with NaOCl would make the enamel crystals more accessible to the etching solution, resulting in a clinically more favorable etched surface.[23]

Few studies have evaluated the adhesion of adhesive resin to hypomineralized enamel and suggested some methods to improve the bonding interface. Pretreatment of hypomineralized enamel with 5% NaOCl has been recommended to remove excess enamel proteins (deproteinization), thus improving the bond strength.[21,23]

William *et al*. recommended initial etching of the hypomineralized defect with 37% phosphoric acid, applying

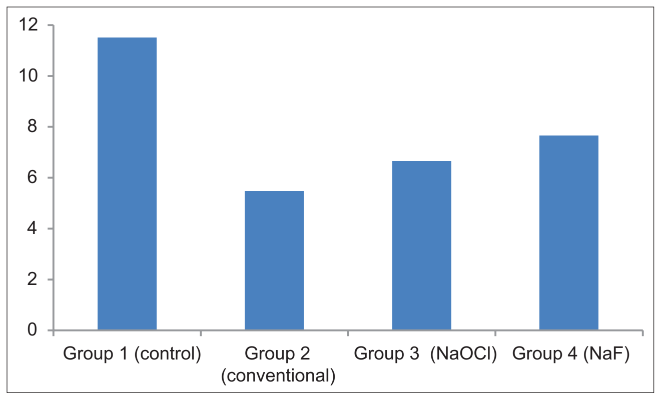
Table 3: Presents the results of the *post hoc* test wherein each group's mean shear bond strength has been compared with the mean of the other three groups

(I) Groups	(J) Groups	Mean difference (I-J)	Std. error	Sig.	95% confidence interval	
					Lower bound	Upper bound
1	2	6.0250000	0.3923762	0.000**	4.968242	7.081758
	3	4.8460000	0.3923762	0.000**	3.789242	5.902758
	4	3.8540000	0.3923762	0.000**	2.797242	4.910758
2	1	-6.0250000	0.3923762	0.000**	-7.081758	-4.968242
	3	-1.1790000	0.3923762	0.024*	-2.235758	-0.122242
	4	-2.1710000	0.3923762	0.000**	-3.227758	-1.114242
3	1	-4.8460000	0.3923762	0.000**	-5.902758	-3.789242
	2	1.1790000	0.3923762	0.024*	0.122242	2.235758
	4	-0.9920000	0.3923762	0.072*	-2.048758	0.064758
4	1	-3.8540000	0.3923762	0.000**	-4.910758	-2.797242
	2	2.1710000	0.3923762	0.000**	1.114242	3.227758
	3	0.9920000	0.3923762	0.072*	-0.064758	2.048758

*The mean difference is significant at the 0.05 level.

Table 4: ANOVA

	Sum of squares	df	Mean square	*F*	Significant
Between groups	204.313	3	68.104	88.470	0.000
Within groups	27.713	36	0.770		
Total	232.025	39			



Graph 1: Graphical presentation of intergroup comparison

5% NaOCl and then re-etching the enamel surface before resin placement. This technique provides better bonding and reduces the amount of microleakage.[24] These findings are in line with the results of present study, which also shows an increase in SBS in samples treated with NaOCl.

Some authors believe that self-etching adhesives bond better to hypomineralized enamel than total-etch systems. However, Adebayo *et al*. detected that the bond strength of self-etch adhesives was not influenced by enamel hardness.[25]

In general, there are a limited number of studies that have evaluated effect of fluoride treatment in AI cases. Fluoride treatment before acid etching of enamel can restore the mineral lost during lesion formation while providing etching patterns that are suitable for composite placement. Schmidlin *et al*. reported that fluoride-treated, acid-etched demineralized enamel allowed good penetration of bonding agent. This also can be attributed to increased SBS.[15]

Few more studies have also predicted that the bond strength of resin placed over fluoride treated caries-like lesions would be comparable to that of the normal enamel. Although they did not measure SBS, Scanning Electron Microscope (SEM) revealed suitable etching patterns.[17,26]

With higher concentration topical fluoride vehicles (such as NaF gels), CaF_2 is precipitated on the enamel surface. This CaF_2 acts as a fluoride reservoir that is released when pH falls. Thus, gels deliver fluoride to the surface of enamel and to the subsurface hypomineralized lesions, where it forms deposits of CaF_2 and provides a reservoir of fluoride ions, and the amount of fluoride deposition in the subsurface lesion is greater after topical applications with such high-concentration fluoride applications.[27]

There is no clinical equivalency on the effectiveness of 1 min fluoride gel applications, but there are considerable data on remineralization and caries prevention for professionally applied topical fluoride of 4 min.[28,29]

A limitation of the present study was that it determined the short-term effects of different surface treatments in AI cases, while in clinical conditions, brackets are generally left in the oral cavity for nearly 2 years or even more. Hence, further research is required in this field to find more suitable protocols to be followed while bonding brackets in AI cases.

CONCLUSION

The following conclusions were drawn from the study:

1. Brackets bonded by conventional technique showed lower SBS as compared to NaOCl and NaF in AI cases.
2. The application of 2% NaF gel for 4 min before acid etching of hypomineralized tooth surface shows significantly higher SBS as compared to conventional and NaOCl group in AI cases.

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Conflicts of interest

There are no conflicts of interest.

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