Original Article

Shear Bond Strength Differences of Types of Maxillary Deciduous and Permanent Teeth Used as Anchor Teeth

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ABSTRACT

Objective: To compare the bond strengths of identical orthodontic brackets bonded to maxillary deciduous and permanent teeth, which were used as anchor teeth in sectional edgewise appliance therapy, and to evaluate the modes of bracket/adhesive failure.

Materials and Methods: A total of 28 human maxillary teeth were divided into four groups by tooth type: permanent first premolars (group I), permanent second premolars (group II), deciduous canines (group III), and deciduous second molars (group IV). Each group consisted of seven teeth. Metal premolar brackets were bonded to these specimens using an acid-etching adhesive system. Shear bond strengths were measured using a universal testing machine, and the bracket/adhesive failure modes were evaluated with the Adhesive Remnant Index.

Results: The shear strengths of the bonds on the deciduous canines and second molars were significantly lower than those on the permanent first and/or second premolars. There were no significant differences in shear bond strength between the permanent first and second premolars, and between the deciduous canines and second molars. The shear bond strengths of all four tooth types were higher than the clinically sufficient range of strengths from 6 to 8 MPa. Bond failure at the enamel-adhesive interface occurred more frequently in the deciduous second molars than in the permanent first premolars.

Conclusions: There were significant differences in shear bond strength among different permanent and deciduous tooth types, but deciduous teeth could be used as anchor teeth in orthodontic treatment with sectional edgewise appliances.

KEY WORDS: Tooth type; Shear Bond Strength; Adhesive Remnant Index score

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INTRODUCTION

A two-by-four sectional edgewise appliance has been used for early orthodontic treatment of dental (functional) anterior crossbites, maxillary incisor crowding, and maxillary impacted (unerupted) incisors in the mixed dentition.[1–3] For the treatment of these malocclusions, the sectional edgewise appliance has been applied more frequently to the maxillary dentition than to the mandibular dentition. To facilitate correction of the anterior crossbite and alignment of the maxillary ectopic/impacted incisor in early orthodontic treatment, orthodontic brackets might be bonded not only to premolars, but also to deciduous canines and molars in addition to the two permanent maxillary first molars and four permanent incisors. These premolars and deciduous teeth are used to reinforce anchorage in sectional edgewise therapy.[3]

The bonding characteristics of orthodontic brackets have been evaluated using shear and tensile bond strengths,[4–8] adhesive remnant indices,[4,7,8] probability of bracket failure,[4,8] and survival times of bonded brackets.[9] The bond strength of brackets to extracted human teeth provides clinicians with useful information on the adhesive systems used in edgewise appliance therapy. Most of the previous studies of bond strength used human premolars,[7,8,10,11] and a few used human incisors, canines, and molars[5,6] or bovine teeth.[12] Bovine enamel has the advantages of easy availability and similarities in physical properties and composition to human enamel.[13] It has been reported that bovine enamel is a reliable substitute for human enamel in adhesion tests,[14] although bond strength to bovine enamel was 21% to 44% lower than that to human enamel.[13] In an investigation of the shear bond strengths of brackets to 12 different human permanent teeth, Hobson et al[4] showed that tooth type had a significant effect on bond strength, and suggested that, to achieve meaningful comparisons, bond strength measurements should be made using the same tooth type, or appropriate stratification of groups of test teeth should be used. To the authors' knowledge, no study has been made as yet to examine the effect of human deciduous tooth types on bond strength.

The purpose of this study was, therefore, to determine the effects of different permanent and deciduous tooth types on the bond strengths of identical orthodontic brackets and on the bracket/adhesive failure modes. The authors selected the maxillary permanent and deciduous teeth that are used most commonly as anchor teeth in orthodontic treatment with sectional edgewise appliances.

MATERIALS AND METHODS

The protocol was approved by the local Committee of Ethics. Informed consent was obtained from all participants in this study, who had been given necessary information about the study in writing and/or orally. Human maxillary first premolars (group I), maxillary second premolars (group II), maxillary deciduous canines (group III), and maxillary deciduous second molars (group IV) were collected for use in this study. Each group consisted of seven teeth. These extracted teeth were washed in water to remove any traces of contamination and stored in a solution of 0.1% thymol at 4°C prior to use. The criteria for tooth selection included intact buccal enamel with no pretreatment chemical agents, no cracks from extraction, no hypoplastic enamel, and no caries.

Metal premolar standard edgewise brackets with a 0.018-inch slot (Victory series; 3M Unitek, Monrovia, Calif) were used in this study. The average bracket base area was 9.94 mm^2.

The brackets were bonded to the teeth with an acid-etching adhesive system, according to the manufacturer's instructions. The buccal surface of each tooth crown was polished with a mixture of water and fluoride-free pumice in a rubber prophylactic cup for 10 seconds. Each tooth was then rinsed with a water spray for 10 seconds and dried with an oil- and moisture-free air stream. The buccal enamel surface was etched with 35% phosphoric acid gel (3M Unitek) for 15 seconds and then thoroughly rinsed and dried. A frosted appearance indicated successful etching. A thin uniform layer of Transbond XT primer (3M Unitek) was applied to the etched enamel surface, and Transbond XT adhesive (3M Unitek) was applied to the bracket base. The bracket was placed on the buccal surface of the tooth and pressed firmly into place to express excess adhesive from the margins of the bracket base. Excess adhesive was removed with an explorer before curing. After positioning, the brackets were light-cured immediately with an Ortholux LED curing light (3M Unitek) for 10 seconds (5 seconds mesially and 5 seconds distally on each tooth).

The root of each tooth that was bonded to a bracket was cut off with a separating disk. The tooth crowns were embedded in the specimen holder ring with self-curing acrylic resin, so that the buccal enamel surface was parallel to and projected above the brim of cylindric specimen holder rings. All specimen holder rings with the embedded teeth were stored in distilled water at 37°C for 24 hours.

A universal testing machine (EZ Test; Shimadzu, Kyoto, Japan) was used to test the shear bond strength. The specimen holder rings were arranged in this machine so that the load applied to the occlusal bracket wings, with a force in the occlusogingival direction, was parallel to the buccal enamel surface. The force required to shear off the bracket was recorded in Newtons at a crosshead speed of 1.0 mm per minute. The shear bond strength (MPa) was then calculated by dividing the shear force by the bracket base area.

After the shear bond strength was tested, the bracket bases and the enamel surfaces were examined through a stereomicroscope with a magnification of 8× by one investigator to evaluate the amount of adhesive remaining on the tooth. The Adhesive Remnant Index (ARI) was used to assess the quantity of adhesive remaining on the enamel surface.[15] ARI scores ranged from 0 to 3: 0, no adhesive remained on the tooth in the bonding area; 1, less than half of the adhesive remained on the tooth; 2, more than half of the adhesive remained on the tooth; and 3, all the adhesive remained on the tooth with a distinct impression of the bracket base.

Statistical Analysis

Statistical analyses were performed with the software StatMate III (ATMS, Tokyo, Japan). The mean

Table 1. Descriptive Statistics for Shear Bond Strength of Four Groups and Tukey Multiple-Comparison Tests

Groups	n	Shear Bond Strength (MPa)			Tukey Test	
		Mean	SD	Range	Comparison of Group	Significance[a]
Group I	7	11.92	2.51	8.56–12.90	I vs II	NS
					I vs III	NS
					I vs IV	$P < .05$
Group II	7	12.92	2.22	10.36–15.44	II vs III	$P < .05$
					II vs IV	$P < .01$
Group III	7	8.18	2.77	4.81–13.19	III vs IV	NS
Group IV	7	7.25	4.06	3.76–13.27		

[a] NS indicates not significant.

Table 2. Distribution of ARI Scores of the Four Groups

Group	ARI Score			
	0	1	2	3
Group I	0	4	2	1
Group II	1	6	0	0
Group III	2	3	1	1
Group IV	4	3	0	0

bond strengths, standard deviations, and ranges were calculated for each of the four groups. A one-way analysis of variance (ANOVA) was used to determine whether significant differences in shear bond strength existed among these four groups. If a significant difference was present, post hoc Tukey tests were used to identify which groups were different from each other. A nonparametric Kruskal-Wallis test was used to test significant differences between these groups with regard to ARI scores.

RESULTS

The shear bond strengths of tooth groups and the results of post hoc Tukey tests are shown in Table 1. The one-way ANOVA showed significant differences in shear bond strength among the four groups. The post hoc Tukey tests showed significant differences in shear bond strength between groups I and IV, between groups II and III, and between groups II and IV. The highest mean bond strength was found in group II and the lowest in group IV. The distribution of ARI scores for each group is shown in Table 2. The Kruskal-Wallis test showed significant differences in ARI scores between groups I and IV ($P < .05$). Bond failure at the enamel-adhesive interface occurred more frequently in group IV teeth than in group I teeth.

DISCUSSION

In this study, one-way ANOVA and post hoc Tukey tests showed that the shear bond strengths of maxillary deciduous and permanent tooth types were significantly different. However, there were no significant differences in shear bond strength between different types of permanent teeth or between different types of deciduous teeth. This finding supports the observation made by Hobson et al,[4] who demonstrated that there was no significant difference in shear bond strength between maxillary first and second premolars. In the present study, the deciduous canines had significantly lower shear bond strength than the permanent first premolars, and the deciduous second molars had significantly lower shear bond strength than the permanent first and second premolars, thus clearly showing that the shear bond strengths of the deciduous teeth were significantly lower than those of the permanent teeth. Only a few studies have ever been conducted concerning the bond strengths of orthodontic brackets to deciduous teeth.[11,16] Our findings that deciduous teeth had significantly lower shear bond strengths than permanent teeth are consistent with those by Endo et al[11] and contradict those reported by Ergas et al,[16] in that the latter study found no significant differences in shear bond strength between brackets bonded to deciduous molars and those bonded to permanent premolars.

It could be speculated that the significantly lower shear bond strength found in the present study for deciduous teeth vs permanent teeth might be a result of the enamel surface structure and the adhesive thickness between the bracket base and the enamel surface. The outer prismless enamel layer is more commonly found on deciduous teeth than on permanent teeth.[17,18] Ripa et al[17] reported that the area on the labial surface where the prismless enamel layer exists most widely covers the middle third of the tooth crown of deciduous teeth, whereas this area covers the gingival third of permanent teeth. This middle third area in deciduous teeth corresponds to the position where the brackets are bonded. Whittaker[18] demonstrated that, on the surface area where brackets were bonded, the percentage of teeth with the most frequent prismless enamel layer width (16 to 45 μm) was higher on deciduous teeth than on permanent teeth. These variations in the frequency and distribution of prismless enamel between different tooth types and between different sites on the same tooth type may contribute to the difference in shear bond strength between permanent and deciduous teeth. After acid-etching conditioning, the outer prismless enamel layer exhibits a shallow etching pattern[19] and limited random porosity,[20] creating insufficient adhesive resin penetration into the enamel surface and resulting in the lower bond strength on deciduous teeth than on permanent teeth, as shown in this study.

It has been reported that deciduous tooth enamel has higher percentages of moisture and organic contents and a lower percentage of inorganic contents than permanent tooth enamel.[21–23] The structure of deciduous tooth enamel, with its low inorganic and high organic contents, may produce poorly developed etching patterns and may be also responsible for the lower bond strength. This may suggest that much more time should be spent on etching in the case of deciduous teeth than in permanent teeth if greater bond strength is to be achieved.

The bases of the brackets used in this study are designed to match the enamel surface configurations of first and second premolars. The enamel surface configuration of the deciduous canines is similar to that of the premolars, whereas the configuration of the deciduous second molars is more complex than that of the premolars, thus causing the adhesive thickness between the bracket base and the deciduous enamel surface to increase. The increased adhesive thickness caused by the application of premolar brackets to the deciduous canines and second molars may be another contributor to lower bond strength in the deciduous teeth. The complex configuration of the deciduous second molars may be also responsible for the large standard deviations and ranges in group IV, indicating that the shear bond strength of these teeth varies widely with bonding techniques.

No published studies have investigated the effect of deciduous tooth types on the shear bond strength of orthodontic brackets. The present study found that the shear bond strengths of all four tooth types were higher than the clinically acceptable range of 6 to 8 MPa.[24] The values for shear bond strengths to the deciduous canines and second molars in this study were very similar to those observed by Endo et al,[11] who measured the shear bond strengths by using the two groups of deciduous teeth, each containing the same numbers of deciduous canines and first and second molars. Although the deciduous teeth had significantly lower shear bond strengths than the permanent teeth in this study, the values of the shear bond strengths to the deciduous canines (8.18 MPa) and second molars (7.25 MPa) did not constitute an obstacle to successful clinical bonding, because these values were relatively high and beyond or within the range of 6 to 8 MPa,[24] and because the deciduous teeth were used as the anchor teeth, so they were not forced to change their position.

In our study, bond failure at the enamel-adhesive interface occurred more frequently in the deciduous second molars than in the permanent first premolars. This might have reflected the insufficient penetration of adhesive resins into the surfaces of the deciduous second molars. Our findings that there were significant differences in shear bond strength, but no significant differences in the distribution of ARI scores, between groups II and III and between groups II and IV support some previous findings[6,11,25] that the amount of residual adhesive resins might not be related to shear bond strength.

CONCLUSIONS

a. There were significant differences in shear bond strength among different types of permanent and deciduous teeth.
b. The shear bonding strengths to the maxillary deciduous canines and second molars were lower than those to the maxillary permanent first and/or second premolars.
c. There were no significant differences in shear bond strength between maxillary permanent first and second premolars or between maxillary deciduous canines and second molars.
d. The shear bond strengths of all four tooth types were higher than the clinically sufficient range of strength of 6 to 8 MPa.
e. Bond failure at the enamel-adhesive interface occurred more frequently in the deciduous second molars than in the permanent first premolars.
f. The deciduous teeth could be used as anchor teeth in orthodontic treatment with sectional edgewise appliances.

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REFERENCES

1. McKeown HF, Sandler J. The two by four appliance: A versatile appliance. *Dent Update.* 2001;28:496–500.
2. Endo T, Mizutani Y, Ozoe R, Kubota M, Simooka S. Effects of early treatment of maxillary incisor crowding by using two bands and four brackets (2×4) mechanotherapy. *Ped Dent J.* 2004;14:87–94.
3. Tal E, Kupietzky A. Orthodontic alignment of permanent incisors following previous trauma of a primary tooth. *Pediatr Dent.* 2000;22:71–72.
4. Hobson RS, McCabe JF, Hogg SD. Bond strength to sur-

face enamel for different tooth types. *Dent Mater.* 2001;17:184–189.

5. Retief DH, Busscher HJ, de Boer P, Jongebloed WL, Arends J. A laboratory evaluation of three etching solutions. *Dent Mater.* 1986;2:202–206.
6. Legler LR, Retief DH, Bradley EL, Denys FR, Sadowsky PL. Effects of phosphoric acid concentration and etch duration on the shear bond strength of an orthodontic bonding resin to enamel. An in vitro study. *Am J Orthod Dentofacial Orthop.* 1989;96:485–492.
7. Carstensen W. Effect of reduction of phosphoric acid concentration on the shear bond strength of brackets. *Am J Orthod Dentofacial Orthop.* 1995;108:274–277.
8. Hobson RS, Ledvinka J, Meechan JG. The effect of moisture and blood contamination on bond strength of a new orthodontic bonding material. *Am J Orthod Dentofacial Orthop.* 2001;120:54–57.
9. Hobson RS, McCabe JF, Rugg-Gunn AJ. The relationship between acid-etch patterns and bond survival in vivo. *Am J Orthod Dentofacial Orthop.* 2002;121:502–509.
10. Grubisa HS, Heo G, Raboud D, Glover KE, Major PW. An evaluation and comparison of orthodontic bracket bond strengths achieved with self-etching primer. *Am J Orthod Dentofacial Orthop.* 2004;126:213–219.
11. Endo T, Ozoe R, Shinkai K, Shimomura J, Katoh Y, Shimooka S. A comparison of shear bond strength of orthodontic brackets bonded to deciduous and permanent teeth. *Am J Orthod Dentofacial Orthop.* In press.
12. Sfondrini MF, Cacciafesta V, Scribante A, De Angelis M, Klersy C. Effect of blood contamination on shear bond strength of brackets bonded with conventional and self-etching primers. *Am J Orthod Dentofacial Orthop.* 2004;125:357–360.
13. Oesterle LJ, Shellhart WC, Belanger GK. The use of bovine enamel in bonding studies. *Am J Orthod Dentofacial Orthop.* 1998;114:514–519.
14. Nakamichi I, Iwaku M, Fusayama T. Bovine teeth as possible substitutes in the adhesion test. *J Dent Res.* 1983;62:1076–1081.
15. Artun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. *Am J Orthod.* 1984;85:333–340.
16. Ergas RP, Hondrum SO, Mathieu GP, Koonce JD. In vitro evaluation of an adhesive monomer as a bonding agent for orthodontic brackets to primary teeth and nickel-chromium ion crowns. *Pediatr Dent.* 1995;17:204–206.
17. Ripa LW, Gwinnett AJ, Buonocore MG. The ‘‘prismless’’ outer layer of deciduous and permanent enamel. *Arch Oral Biol.* 1966;11:41–48.
18. Whittaker DK. Structural variations in the surface zone of human tooth enamel observed by scanning electron microscopy. *Arch Oral Biol.* 1982;27:383–392.
19. Kanemura N, Sano H, Tagami J. Tensile bond strength to and SEM evaluation of ground and intact enamel surfaces. *J Dent.* 1999;27:523–530.
20. Gwinnett AJ. Human prismless enamel and its influence on sealant penetration. *Arch Oral Biol.* 1973;18:441–444.
21. Bird MJ, French EL, Woodside MR, Morrison MI, Hodge HC. Chemical analyses of deciduous enamel and dentin. *J Dent Res.* 1940;19:413–423.
22. LeFevre ML, Manly RS. Moisture, inorganic and organic contents of enamel and dentin from carious teeth. *JADA and D Cos.* 1938;25:233–242.
23. Armstrong WD, Brekhus PJ. Chemical constitution of enamel and dentin I. Principal components. *J Biol Chem.* 1937;120:677–687.
24. Reynolds IR. A review of direct orthodontic bonding. *Br J Orthod.* 1975;2:171–178.
25. O'Brien KD, Watts DC, Read MJF. Residual debris and bond strength—is there a relationship? *Am J Orthod Dentofacial Orthop.* 1988;94:222–230.