Areas Requiring Further Research in Testing of Orthodontic Shear Bond Strengths

JOSE C. DE CASTRO, DDS, MOrth

The introduction in 1955 of acid etching as a simple method of increasing the adhesive capability of enamel surfaces led to a new era in orthodontics.[1] Direct bonding of brackets, reported in 1965 by Newman[2] and then in 1967 by Mitchell,[3] became one of the most valuable procedures ever introduced in terms of reducing both orthodontic treatment time and chairtime, as well as allowing better oral hygiene during treatment.

Since then, so many tests of the shear bond strengths of orthodontic adhesives have been published that one might conclude no further research is necessary. On the contrary, this article suggests new approaches for future studies.

Adhesive Strength and Enamel Damage

Precious time is devoted in any busy orthodontic practice to removing adhesive remnants from enamel surfaces and replacing debonded brackets. Since enamel is lost whenever it is etched or adhesive residue is removed,[4] these repeated procedures can lead to tooth damage, adding to the problems of unbalanced forces and potential soft-tissue injuries from incomplete appliances.

Dr. Castro is in the private practice of orthodontics at Rua Padre Anchieta 621, São Vicente, SP 11310-040, Brazil; e-mail: drcastrojc@uol.com.br.

Orthodontic adhesives and attachments should be capable of withstanding normal forces of mastication, loads exerted by archwires, and even some abuse by the patient. Any orthodontic adhesive should produce clinically acceptable shear bond strengths while permitting bracket removal without damage to the enamel surface.[5-9] The minimum acceptable shear bond strength for orthodontic purposes is between 5.88 and 7.85 MPa, as recommended by Reynolds.[10] The maximum bond strength should be less than the fracture strength of enamel, which is at least 16 MPa.[11] Tests of ceramic brackets, however, have consistently noted enamel fractures in debonding, due to the lack of ductility in the bracket bases compared to stainless steel.[8,12-14]

In vitro testing by universal machines capable of continuous loading has found that with acid etching and composite resin systems, the weakest link is the bracket-resin interface.[5,15-21] Therefore, the practice time consumed in replacing missing brackets could be reduced if more bonding studies were directed at obtaining better adhesion to the bracket base or, in areas such as the upper incisors, a reduced adhesion of the bonding material to the enamel. This would allow even ceramic brackets to be removed so that most of the adhesive remained on the base, without causing enamel damage.[22]

Standardization of Testing Methods

Many authors have concluded that tests of shear bond strength are difficult to compare because of the lack of standardized methods and measurements.[23-27] A number of variables are involved when human or bovine teeth are tested in vitro, including the larger crystal grains of bovine teeth, storage time, storage media, contour variations, and differences in enamel surface composition.[28] In addition, failure rates are different in different areas of the mouth and with different bonding methods and materials, including a variety of brackets and molar tubes.

Two major factors must be isolated when testing orthodontic bonds: the adhesion of the composite resin to human enamel and the adhesion of the attachment base to the composite resin. In shear bond strength testing, especially with metal brackets, the bracket-resin interface often fails before the load reaches the level of failure at the resin-enamel interface.

Pickett and colleagues found that shear bond strengths are significantly higher in vitro than they are after comprehensive orthodontic treatment in vivo.[29] Linklater and Gordon found no significant relationship between in vivo bond failure rates and laboratory testing results, with posterior brackets showing more failures in a clinical environment.[30] One has to conclude that if bench tests more closely replicated clinical conditions, laboratory results would be more reliable.

Bishara and colleagues found a significant difference in shear bond strengths between groups tested at crosshead speeds of 5mm/minute and .5mm/minute.[31] The mandible is capable of chewing as fast as 200mm/second,[32] which is much faster than the standard strain rate of .75 ± .30mm/minute recommended by the ISO for testing bonded specimens.[33] In any case, the ISO parameters are designed for testing adhesion to tooth structure, not for testing orthodontic attachments with two different adhesive interfaces. Using the hand-grip muscular contraction forces on adapted pliers would allow testing with speeds as high as 300mm/second, depending on the load,[34] which would better approximate the closing velocity of the mandible during actual chewing.

A standardized, economical, and accessible synthetic substrate closely resembling human tooth enamel in adhesion to composite resin would be highly useful for in vitro studies of the bond strengths of adhesives to metal or polycarbonate bracket bases. High bond strengths (26.4-29.4 MPa) have been found after acid etching of glass ceramics with relatively low alumina oxide content.[35] In another study where metal brackets were bonded to feldspathic porcelain, the highest bond strengths (15.8 MPa) were obtained when the ceramic surfaces were sandblasted, with posterior silane application.[36] These studies indicate that the surface of a synthetic substrate could be treated to produce a high bond strength at the resin-substrate interface. Any failure would then occur between the resin and the bracket base, which would allow more specific testing of bond strength at that interface.

Conclusion

Future studies of orthodontic shear bond strengths should focus on the following areas:

1. Bonding systems and materials, especially polycarbonate bases, with higher bond strengths at the bracket-resin interface.
2. Adhesives and materials with lower bond strengths at the resin-enamel interface, permitting detachment without enamel damage at the end of treatment.
3. Standardized in vitro testing methods that will allow brackets to be debonded with load forces and head speeds more similar to those found in actual mastication.
4. Effective synthetic substrates resembling human enamel in adhesive strength.

ACKNOWLEDGMENT: I would like to thank J. Leão of the NIST Center for Neutron Research for his help with this article.

REFERENCES

1. Buonocore, M.G.: A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces, J. Dent. Res. 34:849-853, 1955.
2. Newman, G.V.: Epoxy adhesives for orthodontic attachments: progress report, Am. J. Orthod. 51:901-912, 1965.
3. Mitchell, D.L.: Bandless orthodontic bracket, J. Am. Dent. Assoc. 74:103-110, 1967.
4. Pus, M.D. and Way, D.C.: Enamel loss due to orthodontic bonding with filled and unfilled resins using various clean-up techniques, Am. J. Orthod. 77:269-283, 1980.
5. Wang, W.N. and Meng, C.L.: A study of bond strength between light- and self-cured orthodontic resin, Am. J. Orthod. 101:350-354, 1992.
6. Ishikawa, H.; Komori, A.; Kojima, I.; and Ando, F.: Orthodontic bracket bonding with plasma-arc light and resin-reinforced glass ionomer cement, Am. J. Orthod. 120:58-63, 2001.

7. Ewoldsen, N. and Demke, R.S.: A review of orthodontic cements and adhesives, Am. J. Orthod. 120:45-48, 2001.
8. Schaneveldt, S. and Foley, T.F.: Bond strength comparison of moisture-insensitive primers, Am. J. Orthod. 122:267-273, 2002.
9. Pandis, N.; Polychronopoulou, A.; and Eliades, T.: A comparative assessment of the failure rate of molar tubes bonded with a self-etching primer and conventional acid-etching, World J. Orthod. 7:41-44, 2006.
10. Reynolds, I.R.: A review of direct orthodontic bonding, Br. J. Orthod. 2:171-178, 1975.
11. Korbmacher, H.M.; Huck, L.; and Kahl-Nieke, B.: Fluoride-releasing adhesive and antimicrobial self-etching primer effects on shear bond strength of orthodontic brackets, Angle Orthod. 76:843-848, 2006.
12. Eliades, T.; Viazis, A.D.; and Lekka, M.: Failure mode analysis of ceramic brackets bonded to enamel, Am. J. Orthod. 104:21-26, 1993.
13. Liu, J.K.; Chung, C.H.; Chang, C.Y.; and Shieh, D.B.: Bond strength and debonding characteristics of a new ceramic bracket, Am. J. Orthod. 128:761-765, 2005.
14. Rix, D.; Foley, T.F.; and Mamandras, A.: Comparison of bond strength of three adhesives: composite resin, hybrid GIC, and glass-filled GIC, Am. J. Orthod. 119:36-42, 2001.
15. Lee, B.S.; Hsieh, T.T.; Lee, Y.L.; Lan, W.H.; Hsu, Y.J.; Wen, P.H.; and Lin, C.P.: Bond strengths of orthodontic brackets after acid-etched, Er:YAG laser-irradiated and combined treatment on enamel surface, Angle Orthod. 73:565-570, 2003.
16. Nkenke, E.; Hirschfelder, U.; Martus, P.; and Eberhard, H.: Evaluation of the bond strength of different bracket-bonding systems to bovine enamel, Eur. J. Orthod. 19:259-270, 1997.
17. Dickinson, P.T. and Powers, J.M.: Evaluation of fourteen direct-bonding orthodontic bases, Am. J. Orthod. 78:630-639, 1980.
18. Cucu, M.; Driessen, C.H.; and Ferreira, P.D.: The influence of orthodontic bracket base diameter and mesh size on bond strength, S. Afr. Dent. J. 57:16-20, 2002.
19. Bishara, S.E.; Soliman, M.M.A.; Oonsombat, C.; Laffoon, J.F.; and Ajlouni, R.: The effect of variation in mesh-base design on the shear bond strength of orthodontic brackets, Angle Orthod. 74:400-404, 2003.
20. Summers, A.; Kao, E.; Gilmore, J.; Gunel, E.; and Ngan, P.: Comparison of bond strength between a conventional resin adhesive and a resin-modified glass ionomer adhesive: An in vitro and in vivo study, Am. J. Orthod. 126:200-206, 2004.
21. Trimpeneers, L.M.; Verbeeck, R.M.; Dermaut, L.R.; and Moors, M.G.: Comparative shear bond strength of some orthodontic bonding resins to enamel, Eur. J. Orthod. 18:89-95, 1996.
22. Summers, A.; Kao, E.; Gilmore, J.; Gunel, E.; and Ngan, P.: Comparison of bond strength between a conventional resin adhesive and a resin-modified glass ionomer adhesive: An in vitro and in vivo study, Am. J. Orthod. 126:200-206, 2004.
23. Fox, N.A.; McCabe, J.F..; and Buckley, J.G.: A critique of bond strength testing in orthodontics, Br. J. Orthod. 21:33-43, 1994.
24. Akhoundi, M.S.A. and Mojtahedzadeh, F.: Problems in standardization of orthodontic shear bond strength tests: A brief review, J. Dent. Tehran Univ. Med. Sci. 2:36-39, 2005.
25. Linklater, R.A. and Gordon, P.H.: An ex vivo study to investigate bond strengths of different tooth types, J. Orthod. 28:59-65, 2001.
26. Hobson, R.S.; McCabe, J.F.; and Hogg, S.D.: Bond strength to surface enamel for different tooth types, Dent. Mater. 17:184-189, 2001.
27. Eliades, T. and Brantley, W.A.: The inappropriateness of conventional orthodontic bond strength assessment protocols, Eur. J. Orthod. 22:13-23, 2000.
28. Klocke, A.; Tadic, D.; Kahl-Nieke, B.; and Epple, M.: An optimized synthetic substrate for orthodontic bond strength testing, Dent. Mater. 19:773-778, 2003.
29. Pickett, K.L.; Sadowsky, P.L.; Jacobson, A.; and Lacefield, W.: Orthodontic in vivo bond strength: Comparison with in vitro results, Angle Orthod. 71:141-148, 2001.
30. Linklater, R.A. and Gordon, P.H.: Bond failure patterns in vivo, Am. J. Orthod. 123:534-539, 2003.
31. Bishara, S.E.; Soliman, M.; Laffoon, J.; and Warren, J.J.: Effect of changing a test parameter on the shear bond strength of orthodontic brackets, Angle Orthod. 75:832-835, 2005.
32. Hansdottir, R. and Bakke, M.: Joint tenderness, jaw opening, chewing velocity, and bite force in patients with temporomandibular joint pain and matched healthy control subjects, J. Orofac. Pain 18:108-113, 2004.
33. Dental materials—Testing of adhesion to tooth structure, ISO/TS 11405:2003, ANSI, Washington, D.C.
34. Guyton, A.C. and Hall, J.E.: *Textbook of Medical Physiology*, 9th ed., W.B. Saunders, Philadelphia, 1996.
35. Ozcan, M. and Vallittu, P.K.: Effect of surface conditioning methods on the bond strength of luting cement to ceramics, Dent. Mater. 19:725-731, 2003.
36. Schmage, P.; Nergiz, I.; Herrmann, W.; and Ozcan, M.: Influence of various surface-conditioning methods on the bond strength of metal brackets to ceramic surfaces, Am. J. Orthod. 123:540-546, 2003.