

Bonded resins in orthodontics

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The combination of acid-etching and bonding has led to dramatic changes in the practice of orthodontics. Newman¹ began the revolution in orthodontics with the advent of epoxy-bonded attachments. Bonding has evolved and now is used for; placement of attachments, various types of retainers, and resin build-ups which address tooth size and shape problems encountered during orthodontic treatment.

Initially, the bonding of orthodontic attachments was heralded for its numerous advantages (Figure 1). These advantages were specific for different treatment phases. During the initial strap-up of the patient there was less discomfort since separation and band seating were eliminated. Arch length was not increased by band material. Partially erupted teeth were bonded, and aberrant tooth shape did not result in difficult banding and poor attachment position. These advantages resulted in less chair time for the dentist and patient. During the active treatment phase, the appliance was more esthetic, not in contact with gingival tissue, and provided better access for cleaning. These factors provided the potential for better acceptance of the appliance, reduced incidence of caries, and better gingival health. When treatment was complete there was no band space to close and tooth size problems were more easily addressed by stripping or resin build-ups since interproximal areas were accessible.

Several disadvantages soon emerged. Careful isolation of teeth during bonding was necessary to

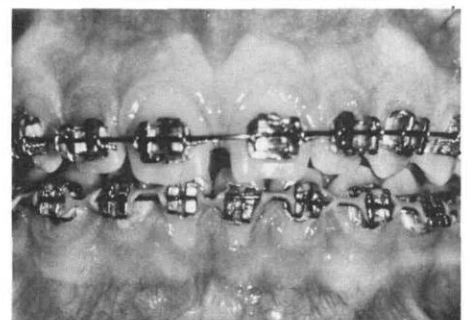
eliminate salivary contamination. Moisture control also made the bonding of partially erupted teeth exceedingly difficult. Some bonding agents were not sufficiently strong, while others would not bond to polycarbonate brackets. Better access for cleaning did not necessarily guarantee better hygiene, especially if resin was allowed to extend beyond the bracket base. The protection of interproximal enamel provided by well-contoured, cemented bands was absent. Finally, the best method for removal of resins from the tooth surface following treatment was not clear — nor were the ramifications of any remaining resin. This paper will discuss the use of resin bonding in several aspects of clinical orthodontics and critical variables related to these procedures.

The Bonded Attachment

The resin: acrylic, diacrylic and combinations of mono- and diacrylics have been used for bonding orthodontic appliances. Acrylic or combination resins have been most successful with polycarbonate brackets, while either acrylic or diacrylic resins were useful with metal brackets.^{2,3} Light polymerized resins were popular with polycarbonate and perforated metal brackets, but the inaccessibility of light to the resin under mesh-back brackets has turned most clinicians toward autopolymerized resins. Concern for details related to the composition of resins and brackets is a necessity if the clinician is to have a compatible bonding system.



Figure 1. These two patients exhibit some of the differences between banded and bonded attachments. (a) The banded attachment covers considerable facial, lingual, and interproximal surfaces and contacts the gingiva. (b) The bonded attachment covers less tooth structure and usually does not contact the gingiva at the time of placement (right).



Several factors may have an effect on the strength of resins. Unfortunately, the type of strength being tested has not been uniform. Tensile strength was believed by some to be the most rigorous test.³ Others have reported shear and torsional strength and found that there was not always uniform strength for all dimensions of a given resin.⁴ The type of force which most accurately simulates *in vivo* activities is still not clear. Even the threshold value of strength necessary to withstand mechanical and extraneous oral forces has only been estimated. The validity of Newman's⁵ 29 kg/cm² or 200 lbs/psi value is not clear. Other experimental variables have also confused the evaluation of resin strength. Testing models, storage time, and storage conditions have not been similar.⁶ Thermal cycling of resins has also been shown to have an effect on the outcome of strength studies.⁷

In spite of these difficulties, several technical factors appear to insure better bonding. Although most *in vitro* fractures of bonds occur at the resin-bracket interface, most clinical failures are at the resin-enamel interface. This is probably due to poor isolation and moisture contamination during bonding.⁸ Stable positioning of the bracket during curing⁹ and a thin layer of resin help to insure maximum strength.¹⁰

According to the theories of bonding, resin with low viscosity should penetrate the etched enamel and provide better strength.¹⁰ Faust, et al.¹¹ found that an increased penetration coefficient of a resin did not increase the tensile bond strength for resin bonded to human enamel. Reynolds and von Fraunhofer¹² also found that an unfilled primer did not enhance acrylic resin tensile strength with human enamel, and that diacrylic resins of different viscosity had similar bond strength. Jassem, et al.⁸ found that a low viscosity sealer had no effect upon either tensile or shear strength when bonded to human enamel *in vitro*. Moin and Dogon¹³ found no difference in shear strength of resin bonded to human enamel between a 78% filled resin plus sealant, a 78% filled resin without sealant, and a 70% filled resin without sealant. However, when only the unfilled resin was used as a bonding agent, a significant decrease in strength was found. The authors suggested that the unfilled resin, or a larger proportion of unfilled resin as a bonding agent (although weaker), may be adequate for mesh-back brackets since resistance to abrasion is not a factor. Unfilled and filled resins which are components of one bonding system can be combined to achieve various dilutions of resin having different viscosities and polymerization times.⁹ This allows the dentist to tailor the resin properties to specific bonding situations. For example, in direct bonding, a quick cure may be desirable compared

with the longer working time needed for indirect bonding.

Sealants have also been advocated for protection of the enamel surface surrounding the bracket base.¹⁰ Ceen and Gwinnett¹⁴ noted that sealants do not form a continuous protective layer of uniform thickness around the bracket. Since the resin will not polymerize in the presence of oxygen, variations in sealant thickness may mean that there are areas with no sealant. They also reported that the layer of unfilled resin has low resistance to abrasion and cannot protect the enamel surface. Zachrisson, et al.¹⁵ in an *in vitro* study, found that sealants for use with orthodontic resins and a traditional pit and fissure sealant did not protect the enamel surface due to poor or incomplete polymerization. In another *in vitro* study, Ceen and Gwinnett¹⁶ found that only a light polymerized sealant was able to protect enamel adjacent to brackets from dissolution and subsurface lesions. They proposed that increased sealant thickness may reduce oxygen inhibition of polymerization. Another approach would be to alter the polymerization process.

It appears, therefore, that the strength of the bond increases when some filler is present in the bonding agent. An unfilled sealer is not necessary to achieve acceptable bond strength and does not afford protection for demineralization adjacent to the bracket base. On the other hand, unfilled resin mixed with compatible filled resin can lead to useful modifications of viscosity and polymerization time. Resins of different composition and strength exhibit acceptable clinical performance.⁶ The lower limit and type of bond strength necessary for acceptable clinical performance are unknown. Making stronger resins for the careless patient is not reasonable since these resins will only be harder to remove (unless a chemical deactivation system can be developed).

The Attachment

Polycarbonate Base. The plastic bracket (Figure 2a) has been judged by many to be more esthetic than the metal base; but it has been handicapped by the need for compatible bonding resins, a lack of strength to resist distortion, and breakage, wire slot wear which leads to loss of tooth control, uptake of water, and discoloration.^{3,5,17} In an attempt to overcome some of these problems, bonding agents have been developed which are sufficiently strong and compatible with polycarbonate bases.³ Modified brackets, which are reportedly stronger, are now available with a metal skeleton to provide rigidity to the tie wings and bracket slot while maintaining acceptable esthetics.

Metal Base. Metal bases which are stronger and somewhat less esthetic have evolved from a per-

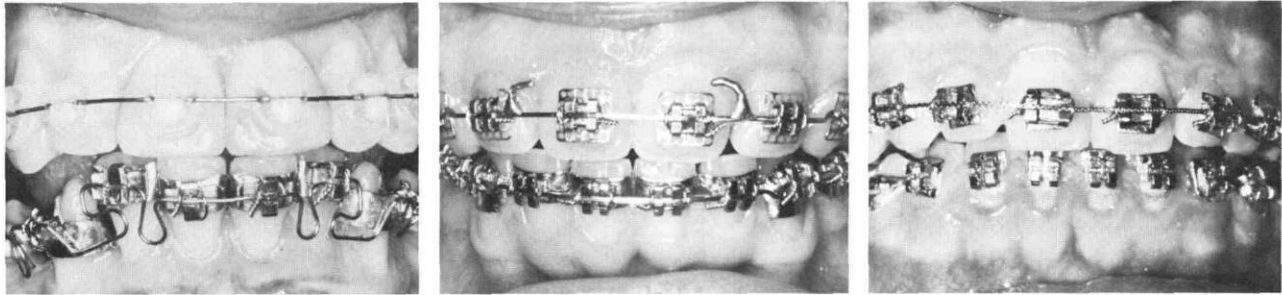


Figure 2. Three different types of attachments are illustrated here. (a) (left) The maxillary anterior teeth have plastic attachments which some feel are more esthetic (courtesy W. R. Proffit). (b) (center) These maxillary anterior teeth have perforated metal base attachments (courtesy H. G. Hershey). (c) (right) These teeth have mesh-back bonded attachments.

forated plate base (Figure 2b) to the present mesh-back (Figure 2c; 3a,b). The size of the metal brackets has also been reduced to improve esthetics. Several factors have been implicated which may play critical roles in the strength of the bracket-resin interface.

The perforated base has been found to provide less tensile³ and shear^{18,19} strength than mesh-back brackets. A photo-etched base exhibited better tensile strength than some mesh-back brackets in one study,¹⁸ but it was significantly less retentive to shear force than finer mesh sizes in another study.²⁰ This may have been due to the amount of air trapped under the photo-etched bracket base, possibly inhibiting polymerization.

The size of the mesh has also been suggested to have an effect on bracket bonding strength. Reynolds and von Fraunhofer²¹ found that larger mesh contributed to increased tensile strength with different viscosity diacrylics. Dickinson and Powers¹⁸ found no relationship between tensile strength and mesh size. Majer and Smith²⁰ found that smaller mesh size led to more shear strength when a lightly filled resin was used.

Reynolds and von Fraunhofer¹² noted that there was no correlation between the area of the mesh and the tensile strength. Dickinson and Powers¹⁸ results for tensile strength were similar to Lopez's¹⁹ for shear strength.

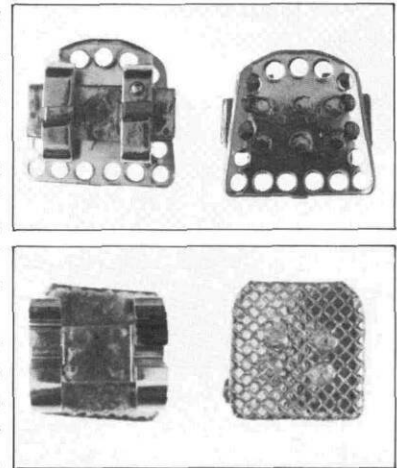
The size and topography of the spotwelds have been mentioned as a factor in the bonding strength equation. Large, globular spotwelds may decrease retentive areas and serve as a location for stress in the bond.^{18,20} Mesh which was attached to the bracket by bracing or laser welding was found to be more resistant to tensile¹⁸ and shear^{19,20} forces.

In summary, plastic brackets can be bonded with sufficient strength if the correct resin is used, with the strength and integrity of the bracket the probable limiting factor. Mesh-back metal brackets have offered adequate strength and good bracket bond integrity when used in conjunction with several different resin compositions. It appears that the area of the mesh bracket base is not a critical factor in

bond strength. This allows clinical use of the smaller, less noticeable, metal bases. The relationship of the mesh size to the resin composition may prove to be a significant interaction. The method of attachment of the mesh to the base may also be a critical factor in preserving retentive strength. Methods which do not reduce retention area and induce stress points due to irregular or protruding welds may offer an improved attachment.

The Rebonded Attachment. Faust, et al.¹¹ reported that the bond-rebond tensile strength differences were not as important as differences between cement or bases. In that study the resin was scraped from the enamel, the surface pumiced and reetched for 60 seconds. Jassem, et al.⁸ found that *in vitro* tensile and shear strength for bonded and rebonded brackets with and without an unfilled sealant resin were not significantly different. Again, enamel surfaces were polished and etched prior to rebonding. Rosenstein and Binder²² found a significantly greater resistance to peel force when the fractured bracket was rebonded with no preparation of the tooth or bracket. This procedure leads to less loss of enamel²³ but may be impractical clinically when using appliances with first order ends (in-out) incor-

Figure 3. Two types of metal bases are shown here. (a) (top) These are front and rear views of a perforated attachment. Note that the resin is free to flow through the holes that are not obliterated by the bracket. (b) The mesh back base is smaller than the perforated base and the rear view on the right demonstrates the retentive areas of the mesh.



The spot welded areas associated with the bracket obliterate the mesh and have been implicated in attachment strength arguments.

porated in the appliance. The added amount of resin could lead to greater offsets than necessary.

The loose bracket can be replaced by repreparing the enamel and rebonding. This should lead to a clinically useful bond with proper bracket positioning.

Attachment Debonding

The challenge in the debonding procedure is to remove the bracket and bond material and return the surface to its pretreatment condition (Figure 4a-c). Ideally the surface would be no more susceptible to pathology than at the pretreatment time. Casperson²⁴ found that resin was present in all debonded teeth he studied when assessed by scanning electron microscopy and energy dispersion radiographic analysis. It appears that removal of unfilled resin is easier and requires less surface altering procedures than the removal of filled resin.^{23,25,26,27} If possible, after bracket removal with a plier, unfilled resin should be carefully removed from the enamel surface with hand instruments and polished.^{25,28} This procedure generally results in a loss of approximately five to eight microns of enamel.^{25,26} The total procedure, from initial etch to final pumice polish, removes approximately 20 to 40 microns of enamel.^{25,26}

The bracket bonded with filled resin should be removed with a plier, excess bond material reduced with a lightly applied tungsten carbide finishing bur at low speed, and the enamel polished with fine pumice (Figure 4d-o).²⁹ If this is accomplished under dry conditions the resin enamel interface will be visible.³⁰ This procedure results in removal of approximately 11 to 25 microns of enamel, and the total enamel removed from etch to pumice polish is approximately 29 to 60 microns.^{25,26} This procedure results in a smooth surface with limited enamel loss.

These recommendations are based upon scanning electron microscopy observations²⁹ and *in vivo*^{25,27} and *in vitro*^{25,26} measurements of enamel loss. Enamel loss judged by tooth surface morphology²⁹ appears to be a misleading method of assessment which gives an impression of very limited enamel loss.²⁶ Dietrich³¹ has also reported one hundred-micron deep enamel fractures following debonding procedure. The enamel loss encountered with routine debonding procedures, exclusive of deep enamel fractures or gouges resulting from injudicious use of hand instruments,²⁸ are probably not significant in terms of total thickness of enamel. The surfaces usually bonded are estimated to have 1500 to 2000 microns of enamel.³² On the other hand, the outer layer of enamel which is removed during these procedures is that which is most rich in fluoride.³³ Therefore, any removal of this layer could cause deleterious effects

to enamel integrity.

There is a 5 micron loss of enamel in the two months following bond and bracket removal. This is considerably greater than the normal loss of enamel²⁷ (approximately 1.6 microns over an 85-day period). By comparison, etched surfaces which are not covered by acrylic lose approximately 3 microns of enamel in 85 days.²⁷ Etched surfaces are also obliterated by a fill-in process. The details of this process are not clear, but Dietrich³¹ has shown that the etched pattern is still evident on enamel after removal of the surface organic components at four months. It has been assumed that during this postdebonding period any residual unfilled or filled resin will gradually be reduced by normal wear. Brobakken and Zachrisson³⁴ have found that there is very little wear of residual unfilled or filled resin during treatment for periods up to one year following treatment. Gwinnett and Ceen³⁵ have demonstrated that there is no increased plaque accumulation on polished, residual unfilled resin. This may not be true for remnants of filled resin that are left during the posttreatment period.

Recent evidence provided by Dietrich³¹ indicates that resin tags may be present at depths of 100 to 170 microns into the enamel. This is a much greater distance than the 25 to 50 microns that has been previously estimated. If conservative methods are utilized for debonding and resin removal to return the enamel surface to a smooth state (such as those cited in this paper), it is unlikely that all the resin present in the tags will be removed. The long-term ramifications of the filled and unfilled resin on these surfaces remains unknown at this time.

Resin Bonded Retainers

Postorthodontic retention has been provided by fixed or removable retainers. In an effort to reduce the visibility of bands and eliminate the need for patient cooperation, clinicians began to use bonded retainers. The tooth-to-tooth bonding of adjacent teeth led to fracture even when the teeth had adjacent Class III preparations filled with composite resin. Next, acrylic reinforced by wire was used to maintain selected teeth in approximation.³⁶ Zachrisson³⁷ has illustrated the use of lingually adapted, 0.032 inch stainless steel wire with retentive hooks bent at each end (Figure 5a). These hooks are necessary to provide mechanical retention and are the only points where resin is applied. An alternative method replaces the retentive hooks with mesh-back pads soldered to either end of the lingual arch (Figure 5b).

Zachrisson³⁷ also illustrated the use of .0175 multi-stranded wire bonded to two or more adjacent teeth in order to control space or tooth rotation (Figure 6). The multi-stranded wire probably allows small positional adjustments which may account for its

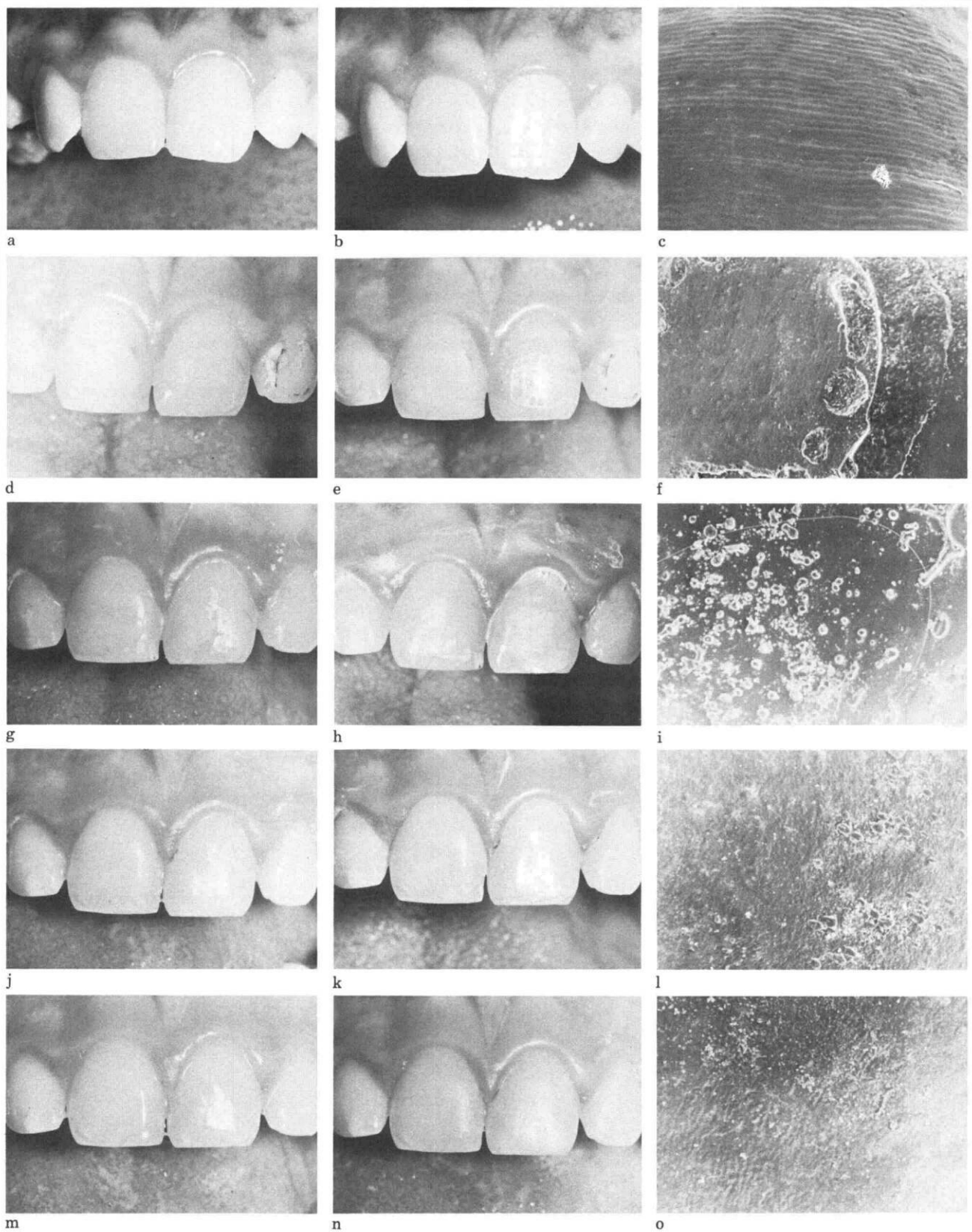


Figure 4. These are views of the enamel surface which illustrate selected points before treatment and during debonding. Each row has a wet and dry clinical view and a comparable 15x scanning electron micrograph of a replica of the enamel surface at the same point. (a,b,c) This is the enamel surface of a young patient prior to any bonding procedures. Note the perikymata which are visible in the dry view and the scanning electron micrograph. (d,e,f) This is the enamel surface immediately after attachment removal. Residual resin is visible in all views. (g,h,i) Incomplete resin removal with a tungsten carbide bur results in this surface. Numerous patients are mistakenly left in this condition. (j,k,l) Following an attempt at thorough removal of resin with a tungsten carbide bur, some resin inadvertently remains. The resin which is evident on the mesial incisal corner of tooth #8 is part of an existing restoration. (m,n,o) Following polishing with fine pumice and a rubber cup, a reasonably smooth surface remains and some perikymata are evident clinically. Small amounts of resin and debris are still evident in the micrograph. In all the clinical views, a better evaluation of the surface is possible under dry conditions.

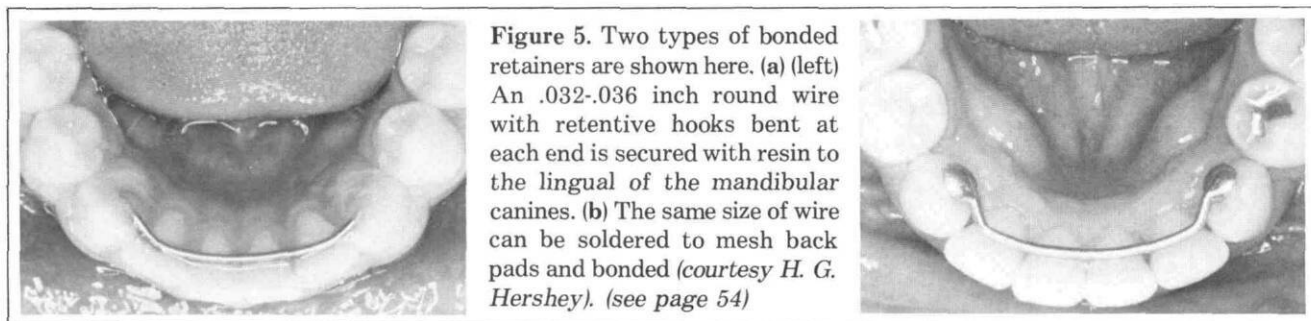


Figure 5. Two types of bonded retainers are shown here. (a) (left) An .032-.036 inch round wire with retentive hooks bent at each end is secured with resin to the lingual of the mandibular canines. (b) The same size of wire can be soldered to mesh back pads and bonded (courtesy H. G. Hershey). (see page 54)

durability. Either method can be applied by direct or indirect bonding procedures. In the maxillary arch, excessive overbite makes these bonded retainers impossible to manage due to occlusal interferences (Figure 6). Trauma that results in permanent deformation of the multi-stranded wire has in some cases led to subsequent tooth movement. However, careful case selection and good patient cooperation and hygiene have led to encouraging results. The long-term success of these procedures has not been reported.

The Resin Build-up

Addition of resin to noncarious teeth during or following orthodontic treatment may be necessary due to tooth size or shape problems.

Tooth Size Problems. Tooth size problems may be the result of localized or generalized increase or decrease in tooth size relative to the opposing arch. These problems are most noticeable in the anterior segments and can be recognized clinically or by the application of Bolton analysis.³⁸ In either case a diagnostic setup can verify the presence of such a problem.

Several conditions contribute to anterior tooth size problems: (1) generalized large or small mandibular anterior teeth relative to the maxillary anterior teeth; (2) generalized large or small maxillary anterior teeth relative to the mandibular anterior teeth; (3) small maxillary lateral incisors; (4) peg-shaped maxillary lateral incisors; or (5) the extraction of one or more mandibular incisors and subsequent space closure.

One type of tooth size problem, the relative mandibular anterior excess, is frequently encountered following orthodontic treatment. Usually maxillary anterior spacing is present. Traditionally, this situation has been resolved by one of the following procedures. Some patients have been treated to reduce overbite and overjet; others have been treated to effect ideal overbite and overjet with spaces left distal to the maxillary lateral incisors. The latter plan may be esthetically objectionable and requires prolonged retention. Occasionally subtle changes in the positioning of the tooth crown may enable one to mask the tooth size problem. Another alternative in small mandibular anterior excess problems is to reduce the width of the lower incisors by stripping the enamel

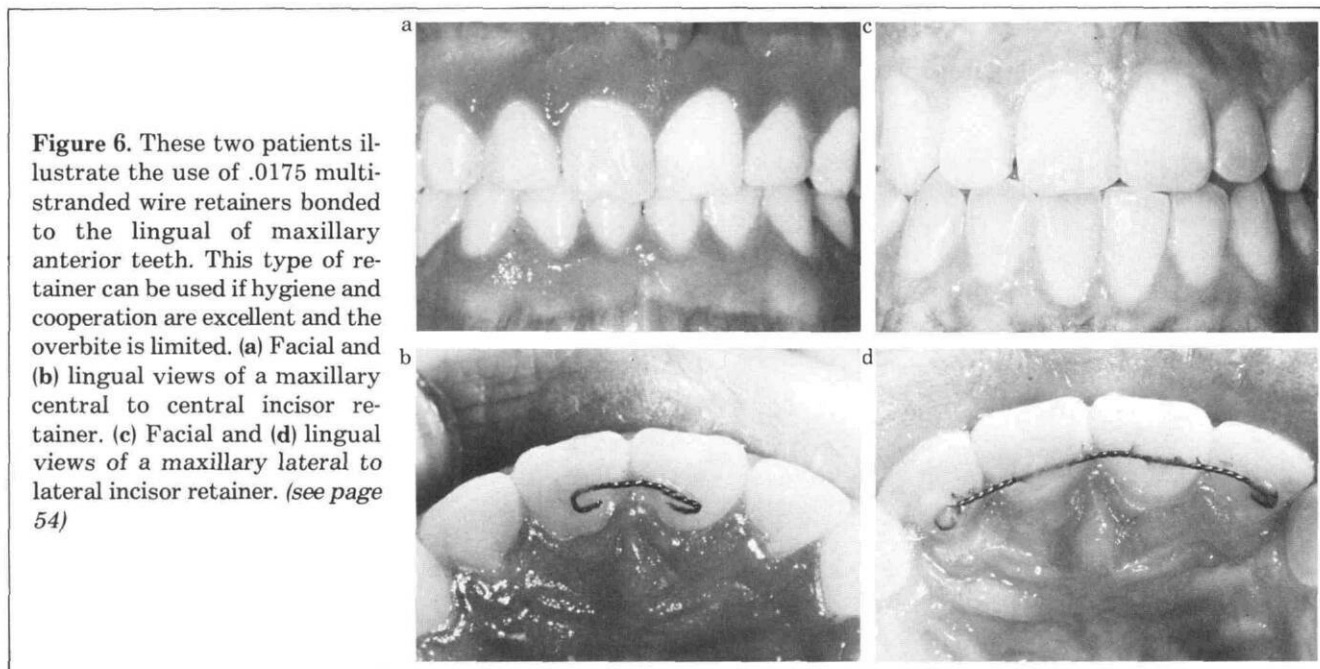


Figure 6. These two patients illustrate the use of .0175 multi-stranded wire retainers bonded to the lingual of maxillary anterior teeth. This type of retainer can be used if hygiene and cooperation are excellent and the overbite is limited. (a) Facial and (b) lingual views of a maxillary central to central incisor retainer. (c) Facial and (d) lingual views of a maxillary lateral to lateral incisor retainer. (see page 54)

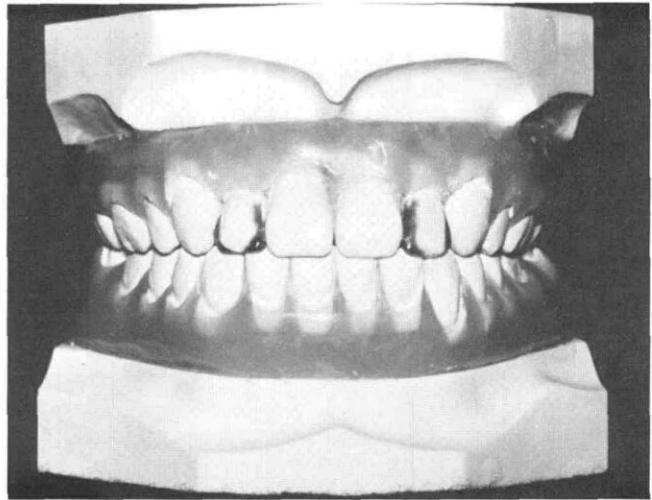
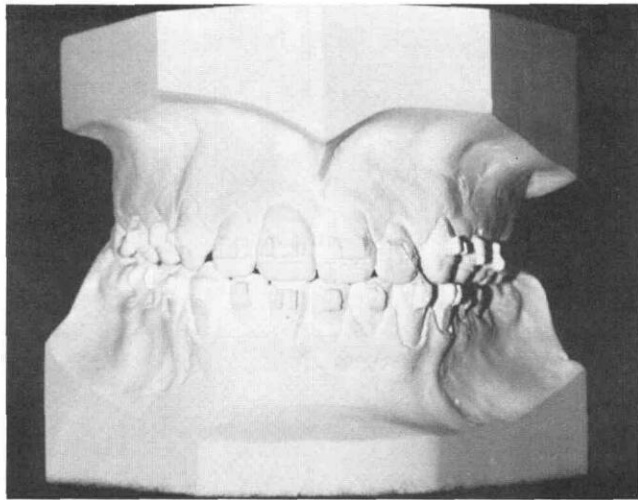


Figure 7a, 7b. This patient exhibited a relative mandibular anterior excess tooth size problem. (a) (left) The patient had limited overbite and overjet even with spaces left distal to the maxillary lateral incisors during the finishing stages of treatment. (b) (right) A diagnostic setup indicated that spaces left mesial and distal to the maxillary lateral incisors could result in an acceptable occlusion and esthetic resin restoration. The proposed restorations are indicated by the dark inlay wax.

thickness. The limitations of this procedure are imposed by the mandibular incisor proximal enamel thickness. Finally, some maxillary anterior teeth have been crowned to increase their mesiodistal width. The esthetic results of this procedure and the reaction of large pulps to tooth preparation are variable. Since the clinical crown length of the incisor changes significantly during the teen years,³⁹ crown margins soon become visible even after careful preparations if the crowning procedure is attempted too early.

New techniques in bonding resins have made another alternative feasible as a semipermanent solution to relative mandibular anterior excess problems. By combining the acid etch technique and resin restorations with careful planning and distribution of the space available, restorations can be added to the interproximal surfaces of maxillary anterior teeth to increase their mesiodistal width.⁴⁰ This is an extension of the technique discussed by Yankelson⁴¹ and provides satisfactory esthetics, retention, limited wear, and acceptable surface texture.⁴² If color or contour changes are produced by wear, these restorations can be polished or modified with the addition of restorative material to provide acceptable esthetics⁴³ and excellent strength.⁴⁴

When a large tooth size problem is suspected, a setup is indicated. Results of the Bolton analysis describe the magnitude of the discrepancy in the majority of cases and serve as a guide for the setup. A setup more closely approximates the true extent of the problem and reveals which of the possible treatment procedures is most acceptable and achievable. The patient illustrated (Figure 7a) exhibited a 1.5

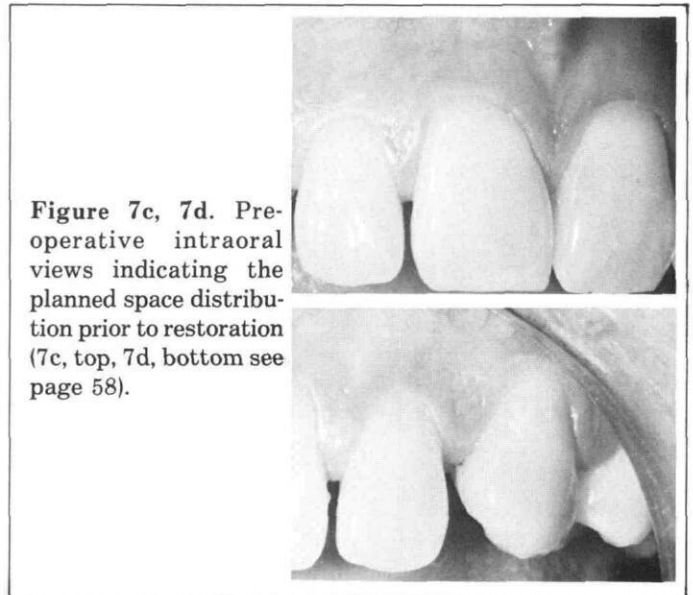


Figure 7c, 7d. Pre-operative intraoral views indicating the planned space distribution prior to restoration (7c, top, 7d, bottom see page 58).

mandibular anterior excess according to the Bolton analysis. The lower incisors had a limited amount of enamel available for stripping and the patient believed that spaces distal to the lateral incisors would be esthetically objectionable. Therefore, it was decided to complete a setup which approximated the proposed tooth position, space distribution and resin build-ups (Figure 7b). The setup provided goals for the orthodontic tooth movement and the restorative treatment.

During the final stages of orthodontic treatment the teeth were moved to the positions indicated by the setup. It is more difficult to control the tooth *in vivo*, and subtle changes in overbite, overjet, and torque can lead to different relationships than

previously planned. Therefore, it is necessary to reevaluate the tooth position at the end of orthodontic treatment.

It is possible to deband and restore teeth at the same visit, although an interim positioner or retainer has advantages in that the gingival tissues are less inflamed and provide a better environment for restorative treatment (Figure 7c, d). Restoration of the teeth using light cured resin is suggested in order to control working time. Careful color selection in natural light prior to rubber dam placement is essential. Either rubber dam or gingiva retraction cord provide access to cervical enamel and control soft tissue. Celluloid strips used in conjunction with firmly placed interproximal wedges aid in the establishment of interproximal contacts and acceptable interproximal contour. Careful attention to tooth morphology is critical if this technique is to be successful. If one attempts to fill too much space with resin, the overcontouring of the surface is obvious.

Following the restorative procedures, gingival tissues require a period of recovery from the retraction; this should resolve in less than an hour. Most often, retainers need to be adjusted or remade at this point. Subsequent spacing or poor resin contours can be repaired quite easily at subsequent appointments.

The case illustrated, as well as others, have demonstrated good immediate (Figures 8 and 9a) and longer (Figures 9b, c) color stability, resistance to wear, and marginal integrity (Figure 8). In addition to offering good esthetics, this system does not alter more than the outer enamel surface. Therefore, this nondestructive or minimally destructive process appears to offer biologically sound semipermanent treatment for young permanent teeth. As the quality of resin products improves, this may evolve to the position of a permanent restorative procedure.

Tooth Shape. Tooth shape problems are most often encountered when maxillary canines are substituted for lateral incisors. Yankelson⁴¹ and Zachrisson⁴⁵ have demonstrated that tooth shape can be enhanced in these cases with careful tooth positioning, selective

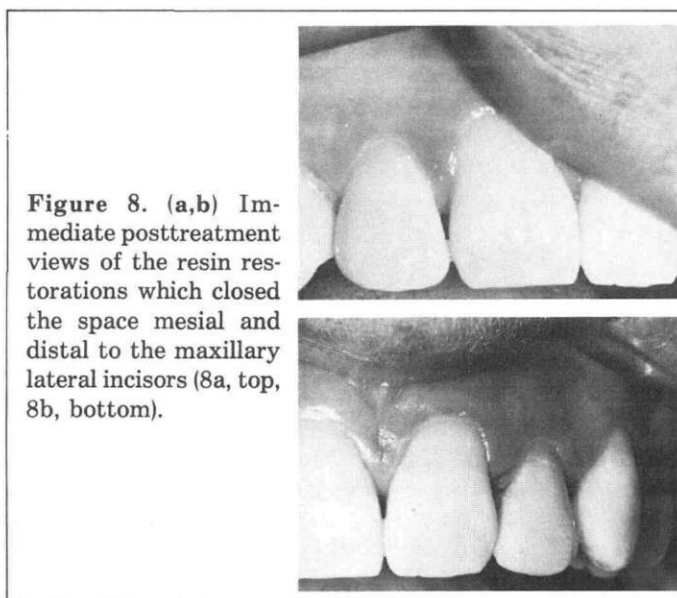


Figure 8. (a,b) Immediate posttreatment views of the resin restorations which closed the space mesial and distal to the maxillary lateral incisors (8a, top, 8b, bottom).

grinding, and the addition of resin to the crowns of the canines. Occasionally, first premolars which are in the canine position need the addition of resin. The resin added to the incisal edge will be subject to more wear than that added at the line angles. Fortunately, most tooth shape modifications are necessary in the area of line angles. Figure 10a and b illustrate the substitution of a maxillary canine and first premolar for maxillary lateral incisor and canine respectively. In this case, resin was added to the mesial and distal line angles of the canine and mesial of the first premolars during the active phase of orthodontics (Figures 10c, d). Generally, modifications made during treatment will have to be refined following debonding.

The addition of resin to the crowns of substituted teeth provides the practitioner with an alternative to tooth reshaping by enamel and dentin reduction in an effort to provide good esthetics. Once again the reversible and non-destructive nature of this technique makes it very acceptable for the young patient.

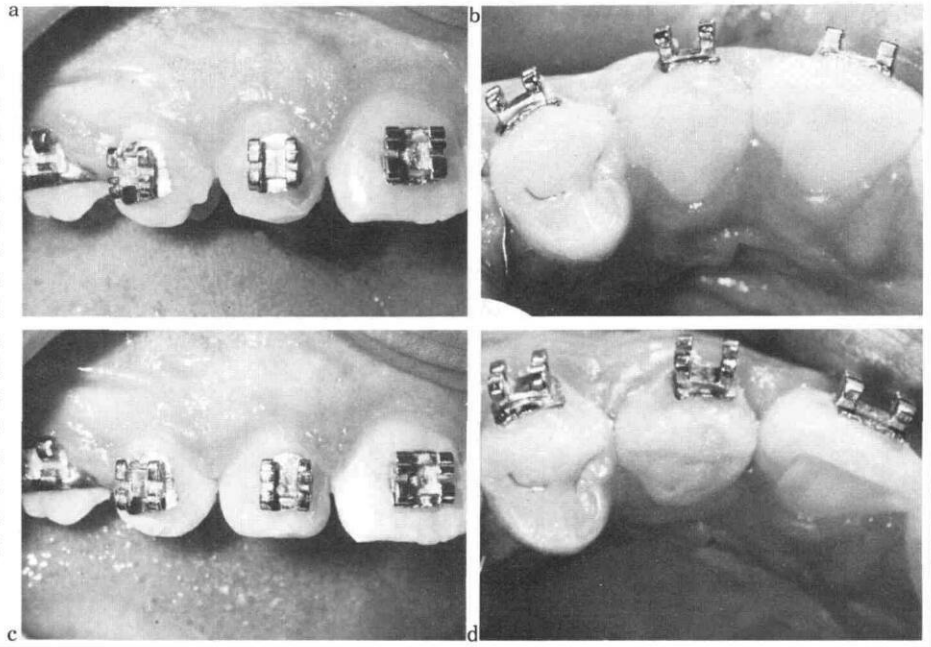
Summary

Resin bonding has changed the practice of orthodontics. This innovation has effected each phase



Figure 9. The patient is illustrated at various posttreatment times to demonstrate the resin appearance. (a) Immediate, (b) (center) one-year and (c) (right) twenty-one months posttreatment conditions.

Figure 10. This patient shows the use of resin to modify tooth contour when substituting a maxillary canine for a lateral incisor and a first premolar for a canine. (a,b) (top, left and right) Pretreatment views during the finishing stages of orthodontic treatment. (c,d) (bottom, left and right) These views are after resin has been added to the mesial and distal incisal edge of the canine and the mesial incisal edge of the first premolar. The resin allows contour modification without gross tooth reduction. The resin can be recontoured following attachment removal.



of treatment as well as posttreatment therapy. Modifications of resin, attachments, and procedures are continuing. Hopefully, each alteration will be carefully planned and based on evidence from *in vitro* and *in vivo* studies. Since these two methods of investigation do not always reflect one another, careful interpretation will be necessary. Finally, long-term data for these procedures is needed to deliver an informed verdict. Until that time, careful study by the practitioner of the available information will be mandatory.

The replica technique used to obtain the scanning electron micrographs was developed by Ms. Cindy Moore, BS, RDH. Ms. Moore also produced the micrographs. Manuscript preparation was provided and expedited by Ms. Pam Andrews.

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Quotable Quote

There is today a growing discrepancy between the science, mathematics, and technology education acquired by high school graduates who plan to follow scientific and engineering careers and those who do not. Scientific and technical literacy is increasingly necessary in our society, but the number of our young people who graduate from high school and college with only the most rudimentary notions of science, mathematics, and technology portends trouble in the decades ahead. Thomas Jefferson's axiom that an enlightened citizenry is the only safe repository control over the ultimate processes of society surely includes the necessity for scientific and technological enlightenment. While students who plan scientific and engineering careers are receiving an adequate educational foundation, more students than ever before are dropping out of science and mathematics courses after the tenth grade, and this trend shows no signs of abating.

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