In vivo Wear of Residual Orthodontic Adhesive After Debonding

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INTRODUCTION

The bonding of orthodontic brackets directly to surfaces of teeth has received a growing amount of attention in the past few years both clinically and in scientific research. Estimates so far suggest up to 93% of orthodontists are involved to some extent with bonding[26] and that bonding has become routine in modern orthodontics[7].

The incentive for this change results from a number of theoretical advantages compared to relatively few disadvantages. Commonly stated advantages of bonded bases over preformed bands include improved gingival health (if excess adhesive is avoided)[29,59]; cosmetic superiority; elimination of a separation and band space closure phase[16]; band seating discomfort is avoided; odd shaped teeth need no special fitting; less area is subject to possible decalcification; Class II restorations can be done with the appliance in place; interproximal stripping can be done as needed at any time during treatment; and some final retention methods may be started before appliance removal[6].

The problem and major research emphasis at one time was in developing an adhesive and bracket combination which would remain attached to the tooth throughout the treatment period, withstanding the oral environment and forces to which it would be subjected. This has now been accomplished to the point where bracket loss is comparable to the number of bands which fail during an active orthodontic treatment period[59]. Studies have reported failure rates of less than 10%[52], 70 out of 1510 (5%)[40], 7% overall and 2% excluding bicuspids[25], 2.7% between December 1976 and December 1977[60], and 3% over 2 years with 1% aside from premolars[32]. Few studies have been done on band failures to establish comparative failure rates.

Orthodontic appliances are only temporary, however, and at least one comparative problem which results from using a bonding system rather than cementation of bands is in the removal of the appliance and adhesive. The bonded adhesive-to-enamel strength, which is enhanced by using the acid etch technique, is by far greater than the adhesion of conventional orthodontic cements to enamel.

Whereas the conventional cements require a rather routine hand scaling and prophylaxis to restore the tooth surface to its pre-treatment condition, the resin residue removal requires a much more tedious procedure if done by hand. Resorting to mechanical rotary abrasives presents the problem of possible tooth surface damage.

Over the past three years a number of studies of the enamel surface by scanning electron microscopy have been done comparing a variety of adhesive removal and polishing techniques. The instruments used and compared include specially designed pliers, hand scalers, ultrasonic scalers, rotary abrasives, and burs. Regardless of the technique, all methods have clearly been found to cause scratches, gouges, grooves, or other surface imperfections[15,30,62]. Moreover, post instrumentation resin remnants were invariably found to remain on all teeth[15,16,30]. A surface deemed satisfactory was obtained with very few of the instruments and in those cases only after final finishing with a pumice slurry[62].

Even if the tooth surface can be restored to a normal appearance, there is still a concern over the consequences of residual adhesive. Weitman and Eames[58] studied plaque accumulation on composite resin in Class V restorations and found them covered with plaque after 24 hours regardless of the finisher used. In contrast, Gwinnett and Ceen[29] studied plaque patterns over a 6 month period in debonded individuals and found the "presence of small resin remnants did not predispose to preferencial plaque accumulation".

The state of the art seems to be to de-emphasize complete removal of remaining resin and simply to "produce an aesthetically and clinically acceptable surface while at the same time minimizing damage to the enamel"[49]. It would then seem appropriate if not obligatory to, as Casperson stated in 1977[16], "perform long term observations of the reaction of this unintended foreign substance on the tooth surface".

Although there have been several suggestions in the literature that residual adhesive might "wear" away in a reasonable amount of time[6,9,29,33], there has been very little in the way of quantitative determinations. The purpose of this study is to approach this possibility with a longitudinal study using an in vivo replication technique.

REVIEW OF THE LITERATURE

The credit for development of the basic fundamentals for clinically successful dental bonding is generally given to M. Buonocore and R. L. Bowen. Buonocore began development of the acid etch technique[11] and Bowen developed the BIS-GMA resin[3] used in most orthodontic adhesives[6,7,23,41,44,46,48]. Since then bonding has become an acceptable clinical procedure due to refinements by numerous researchers.

Some complications involved with bonding and questions which have been approached for answers pertinent to this paper will be reviewed chronologically in five broad areas of discussion. These are:

1. Acid etching and remineralization of enamel
2. Composition of adhesives
3. Debonding and enamel surface study
4. Wear of adhesives
5. Replication techniques for longitudinal studies

ACID ETCHING

In early reports Buonocore[11] used 85% phosphoric acid to etch enamel surfaces prior to application of acrylic resin and found increased adhesion. Buonocore et al.[13] then reported that the basis for extra adhesion after etching was the penetration of prism-like resin tags into the spaces created by the acid conditioning, and suggested a possibility of enhanced chemical union as well.

Lenz and Muhlemann[34] reviewed studies of etched enamel to report on the "remineralization" phenomenon. They found the prism like pattern left by etching disappeared in 2 to 48 days due to deposition of salivary pellicle, and reported that enamel surface marks may be repaired by an upgrowth of calculus like deposits on the pellicle.

Newman and Facq[44] used 50% phosphoric acid for 1 and 2 minutes and found the etched surface returned to normal in 3 to 6 months. They felt that fluoride might be an important factor in remineralization.

Silverstone and Dogon[52] published conclusions from a symposium held on the acid etch technique. In one of the studies presented, various phosphoric acid concentrations and buffered solutions were used to etch and the resultant surfaces studied. They reported unaltered 30-40% phosphoric acid for 60 seconds would create the most favorable surface conditions. The resultant depth of resin tags applied in vitro was reported as 50-60 microns (μ). The enamel thickness under the areas bonded ranges from approximately 1500-2000μ[9,24,25,51].

Arana[1] did a clinical photographic study after etching with a 50% phosphoric acid gel for 2 minutes on 4 individuals of ages 3 months, 25 years, 55 years, and 67 years. He found the enamel "remineralized" faster in younger individuals, with all ages returning to normal surfaces after 48 hours. He concluded that "any fears of damage by etching are essentially groundless".

Silverstone[53] then studied solubility rates for etched enamel. He found a higher solubility rate for a period of 24 hours after which remineralization caused a return to near normal rates. After sealing with resin, followed by grinding until all macroscopic evidences of resin were gone, he found the remaining surface to be less soluble than adjacent sound enamel.

Fitzpatrick and Way[24] developed an enamel depth measurement technique and found an immediate 9.9μ loss of enamel from etching and another 3μ enamel layer prone to loss, in addition to the normal wear, over a 2 month period after the etch. They concluded that the return of an etched surface to normal is primarily a function of reconstitution through pellicle deposition or remineralization rather than abrasive wear.

Brannstrom et al.[7] studied how adhesion to etched surfaces varied under various condtions. They confirmed that etching patterns vary even on the same tooth, so retention would vary with the patterns. They found no etching difference between a gel vs. liquid acid. They found that roughening the enamel surface or pre-treatment with chemical cleaners did not alter the etching effect, and they found no difference in etch quality after pre-treating the surface with fluoride.

Voss and Charbeneau[56] studied differences in resin tags applied to etched ends of enamel rods compared to etched sides of rods in longitudinally cut enamel. They found 5-10μ tags in the rod end sections, and 3-5μ along the sides of etched enamel rods. Jordan et al.[33] have reported a concensus of tag length from 20 to 50μ.

Zachrisson and Arthun[62] summarized recent findings on remineralization reemphasizing that rates of reparative precipitation vary in different people. They pointed out the existing controversy as to the quality of the remineralized material, concluding most likely it is of an apatitic nature, with only minor amounts of impurities. They emphasized that uptake of remineralized material is enhanced by fluoride and suggested flouride rinses after debonding.

ADHESIVE COMPOSITION

One of the earliest clinical reports of bonding on humans was by Newman[43] in 1965. He used an epoxy adhesive which required mixing chemicals, heating the mixture to tachyness, then applying and allowing to gel on the tooth for 15-30 minutes. He had tested the materials on extracted teeth and on mucous membranes of rabbits, concluding it was safe for humans. He reported clinical success up to 10 months at that time. He indicated a need for improvement of the adhesive, notably a shorter curing time.

Bowen had patented his BIS-GMA resin in 1962[3], and resulting products overcame many of the shortcomings found by Newman and others. Variations in resins at this point are so numerous it becomes necessary to have some perspective of polymer chemistry to understand them.

The term resin as used in the dental literature generally is all inclusive referring to synthetic products which have properties similar to organic resins. The chemical groupings of these materials are called resin systems and include the cyanoacrylates, polyamides, polycarbonates, polycarboxylates, polystyrenes, polyurethanes, and those commonly used in dentistry, the epoxies, acrylics, and diacrylates. They are also referred to as polymers due to their linked repetitive chemical structures[17].

The epoxy resins were developed around 1940[5] and were the first of the so-called "miracle" plastics thought to have a future in dentistry[45]. As mentioned, cure rate proved to be a major disadvantage.

Acrylics are chemically organic acids, the most common in dentistry being methylmethacrylate which is used for dentures, unfilled tooth colored restorative materials, plastic orthodontic appliances, and some orthodontic bonding adhesives. Methymethacrylate is reacted with itself to form a thermoplastic polymer which can be powdered to give a solid that can be dissolved by its own monomer (liquid) for further reaction to higher and higher molecular weights[45].

Diacrylates are derived from epoxy resins reacted with various acrylic monomers to make them chemically bifunctional[19]. While the acrylic resins form only linear polymers, diacrylates may be polymerized by cross linking as well, providing greater strength, lower water absorption, and less polymerization shrinkage[25]. Aromatic dimethacrylates produce an even more rigid material[19]. Bowen's resin is such a material, obtained by reacting bisphenol A (the aromatic backbone of the epoxy resin) with glycidyl methacrylate (a species terminated on one end with an epoxy group and on the other with the acrylate)[45], thus called BIS-GMA[4].

Cure rates of this new material can be varied to be ideal, so with that problem solved the next improvement was in strengthening the resin by the use of fillers. Bowen[4] found he could reinforce BIS-GMA with silica powder and superior properties could be obtained by coating the powder particles of 150μ and smaller with vinyl-silane.

Brown et al.[10] reported on the various fillers used, listing silane coated alumino-phosphate, silicate, and borosilicate glass being used in polymethylmethacrylate systems as well as in aromatic dimethacrylates. A quartz filler was also used in one of the dimethacrylate products. Fillers vary from irregular size and shape to more consistent sized rods or spheres.

"Composite" resins is an all inclusive term for these filled resin systems. The inorganic filler phase added comprises in some cases up to 75% by weight and 50% by volume of the material. They have a modulus of elasticity 5 times, compressive strength 3 times, and tensile strength 2 times as great as unfilled resin[18].

Gwinnett and Gorelick[30] defined heavily filled composites as approximately 70% filler and lightly filled at 4% filler. They found that orthodontic brackets were easier to remove from teeth bonded with unfilled or lightly filled resins.

Zachrisson[60] looked at these adhesives studying some effects of filler size. He stated the heavily filled composite* contained large, coarse quartz or silica glass particles of highly variable size with an average of 3-20μ which increased abrasion resistance and modified viscosity. Lightly filled composites+ contain submicron particle fillers of .2-.3μ, and consequently yield a smoother surface which he found to be more hygienic. He questioned whether particle size affected bond strength, referring to Mitchem and Turner[39] who found transverse strength of unfilled BIS-GMA to be similar to filled resins, and that transverse strength of a specific adhesive was not correlated to its retentive capacity in vitro.

From a bonding round table discussion question on adhesive strength[25], Thomas states, "The filler particles and the resin matrix . . . increases the strength of the overall resin mass". Gorelick stated that "the filled BIS-GMA derived composites are stronger clinically than unfilled adhesives",

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* Concise Enamel Bond-composite System, 3M Company, St. Paul, Minn.

\+ Endure, ORMCO Corp., Glendora, Calif.

and defined stronger as "that which helps reduce the frequency of bond failures".

Faust et al.[23] found greater diametral tensile strength of filled diacrylates over unfilled, supporting evidence that fillers add great strength to adhesives. Moin et al.[41] studied shear strengths of unfilled and filled resin combinations, concluding remnant removal to be more difficult with filled resins. Retief and Denys[49] agreed with Gwinnett and Gorelick in suggesting the best practical bonding adhesives are the lightly filled resins which are not too strong so that on debonding, the adhesive will fracture rather than the enamel.

Retief[48] has reported fractures of the enamel occur at tensile forces of 1400 lb./in.^{2}. The study by Faust et al.[23] found orthodontic resins to fracture in a range between 2150 and 6650 lb./in.^{2}. Caspersen[16] stated, "The adhesion to the etched enamel surface then clearly exceeds the tensile strength of the material".

Another aspect of this discussion involves sealants. BIS-GMA is a thick (viscous), sticky resin which is diluted with a dimethacrylate thinner to make the unfilled BIS-GMA sealant. Theoretically this material should flow onto and adapt well to surfaces. Mitchem and Turner[39] concluded that retention of resins was a function of their ability to adapt to the etched enamel surface. Zachrisson[59] felt sealing would increase bond strength while at the same time allow for easier adhesive removal, possibly due to the unfilled adhesive between tooth and filled adhesive being a convenient fracture location. For that reason he suggested a more heavily filled adhesive may fracture off in larger segments on debonding[61]. Overriding these theories, however, is the problem with lack of sealant polymerization due to oxygen inhibition, which is a major weakness of sealants on the market today[25]. Faust et al.[23] found all sealants to have a lower bond strength value, probably due to lack of polymerization.

Sealants will polymerize if applied in thick layers so oxygen exposure is reduced, but the resulting floating of the bracket out of position is a clinical problem. In addition, thin layers of adhesives make stronger joints than thick layers[12,25,49].

DEBONDING

Newman and Facq[44] published an early study of effect of adhesive systems on tooth surfaces using a scanning electron microscope (S.E.M.) and helped establish a technique used often in subsequent detailed studies of debonding. They concluded that "removal of the adhesive and repumicing of the bonded surface restore the tooth surface to its original pumiced appearance".

Hannan and Smith[31] compared the effects of several finishing instruments on surfaces of composite restorative materials and enamel. They found "severe" roughness using sandpaper discs, polyester aluminum oxide discs, and green alpine points. They found margins ditched with a plain steel finishing bur or a cross cut carbide fissure bur. Most satisfactory over all of the above as well as over a fine diamond or a scalpel blade #12 was the surface obtained on enamel or composite with a plain tungsten carbide (TC) bur. They specified low speed and constant waterspray.

Retief[48] searched for calcium in removed adhesive stubs, studying bonded adhesive-enamel interface failures. He found evidence for fractured enamel in all cases.

Zachrisson[59] and many other researchers then started reports on post-treatment evaluations of bonded teeth. At this time Zachrisson suggested the TC bur at low speed to be helpful in completing removal of adhesive.

Caspersen[16] described his debonding technique using orthodontic ligature cutters or scalpel for gross adhesive removal, followed by a fine rotating abrasive wheel, and in some cases polishing with pumice in a rubber cup. He assigned numbers of above 12,000 rpm to high speed and about 2,000 rpm to low speed for handpiece instrumentation.

He then attempted to confirm residual acrylic material on the enamel surface using energy-dispersive x-ray analysis (ED). In this technique the energy levels of secondary radiation from the surface of an irradiated tooth are specific for the component elements from which they are radiating. A photograph of this image field can thus be obtained showing distribution of calcium over a given surface and can be compared to the SEM picture, reportedly confirming residual adhesive.

Caspersen found adhesive to be retained on all teeth. He also found no evidence of space between tooth and resin, reporting therefore, no reason to expect discoloration as a result of the residual material.

Gwinnett and Gorelick[30] did a SEM evaluation of enamel after debonding, comparing hand instruments, green stones, white stones, sandpaper discs, green rubber wheels, TC burs in high speed, plain steel finishing burs at low speed, and acrylic steel burs at low speed, all followed by a medium grade pumice. Their search was for an instrument which would abrade composite without abrading enamel, and "none such was found". Their comments include the finding that green and white stones left grooves remaining even after pumicing, that the TC bur in high speed or steel burs at low speed caused more loss of enamel than other methods, and that pumice after sandpaper discs or green rubber wheels came close to restoring the natural enamel surface. They concluded the carefully cooled green rubber wheel followed by pumicing to be effective while doing the least damage.

Fitzpatrick and Way[24] seated wire into drilled holes in enamel and measured the resulting pit using a silicone impression in vivo. They bonded over the same areas, then debonded using bracket-removing pliers* for bracket and some adhesive removal. The teeth were then smoothed with a 12-fluted high speed bur and pumiced with hard pumice+ in a rubber cup. By measuring the pits they found a total loss of enamel from etching, removal, and clean-up to be around 55μ. They commented that this would indicate that resin tags would therefore be removed in the debonding process.

Burapavong et al.[15] debonded with a ligature cutter and compared results when using hand scalers, ultrasonic scalers, or green stones to remove adhesive, also comparing final surfaces which had or had not been pumiced. They used stereopair photomicrographs to determine depth of damage marks and determined a 9-12μ average, with a 20μ maximum. They felt that holes 10-20μ deep would be a consequence of debracketing. They also found that all treatments left scratches and that while the green stone scratches could not be pumiced out, the surface left by the hand and ultrasonic scalers could be pumiced to near normal. In contrast to

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* E.T.M., Monrovia, Calif.

\+ Zircate, L. D. Caulk, Division of Dentsply International, Milford, Del.

Caspersen, they felt that remaining resin could be largely removed by pumicing and did not find the ED spectroscopy to consistently detect thin films of resin due to the masking effect of the metallic coating needed for the SEM. They suggested the remaining resin may not be of clinical significance.

Retief and Denys[49] have recently published another SEM evaluation of enamel after use of various debonding instruments. Damage which could not be smoothed by pumice was caused by the bracket-remover plier, scaler, superfine finishing diamond, 12 bladed carbide finishing bur in high speed, and the stainless steel finishing bur at 10,000 rpm. They reported the steel bur to be slow in resin removal and that frequent replacement was necessary due to bluntness. They observed satisfactory surface profiles after a series of several sof-lex aluminum oxide finishing and polishing discs as well as a series of three Ceramisté wheels, if followed by pumice in a rubber polishing cup. Their suggested debonding recommendations included the 12 bladed carbide finishing bur at high speed and air cooled to remove the bulk of the resin, then the three graded Ceramisté wheels with light pressure and adequate air cooling (in a dry field for maximum recognition of the resin-enamel interface), and final pumicing using a water slurry of pumice with a rubber cup.

Zachrisson and Arthun[62] published another SEM study also comparing enamel surfaces after treatment with a wide assortment of the common finishing techniques. They evaluated the surfaces using an enamel surface index (ESI) which was a defined system of five gradations. This included defining a "normal" surface and involved the variations of natural perikymata on teeth.

For their study they used only teeth covered completely with perikymata. They found that none of the methods left a perfect surface, and that polishing alone did not remove the resin remnants. Only the 6 fluted plain cut and spiral TC burs at slow speed, followed by polishing, satisfied their next best category of "fine scratches with some perikymata". They noted that the adult normal tooth fits into their third category of "acceptable surface, some scratches, no perikymata".

They reasoned that since the height of these ridges of perikymata are about 10μ, and some ridges remained, that 5-10μ was about the limit of total enamel lost in the entire debonding process. They felt the scratches produced by the TC bur were of little, if any, clinical concern.

During the bonding round table discussion mentioned[25], different debonding procedures were found to be used by each of the panel members. Masunaga removes the bracket and the adhesive with carbide tipped ligature cutters using a cotton roll to protect the incisal edge, then polishes with pumice on a rubber cup. Thomas removes the bracket with a bracket-removing plier, then flakes off the adhesive with a posterior band-removing plier sharpened to a knife edge, then pumices with a medium grit pumice followed by a polishing paste. Zachrisson does the bracket removal with a broach plier, then scrapes most remaining adhesive off with a scaler or pliers. Any remaining material is removed with a plain cut or spiral TC bur at low speed without water cooling. He then uses a rubber polishing disc or pumice and rubber cup for 3-5 seconds per tooth. Gorelick removes the bracket with a sharp beaked instrument and a quickly applied peel force. Any remaining bulk adhesive is then removed with a green rubber wheel with air cooling, reshaping the wheel as needed with a disc. He uses a scaler to clean near the gingiva or in the embrasure areas inaccessible to the rubber wheel. He also may use a high speed fluted finishing bur for bulk removal, stopping short of the enamel. Final polish is done with fine pumice for 5-10 seconds per tooth.

One final possibility reported on by Dragiff[21] involves constructing a compound splint for teeth before debonding, then using a pneumatic handpiece with steel chisel points to remove adhesive. He reported less patient discomfort even with periodontally involved teeth, and stated that he could feel small remnants with the handpiece which could not be easily seen. Final pumicing was done, but no detailed surface study was reported.

WEAR

The subject of wear of resin and teeth in vivo has not been reported on extensively in the literature, and very few good quantitative studies have been done. Several attempts worth noting have been made which establish approximate figures.

Sexson and Phillips[50] studied mechanical brushing of acrylic resins, equating 20,000 strokes with 2 years brushing. They found .2 mm of wear with a brush and tooth powders after 20,000 rotating strokes.

Graben, Stetter, et al.[27] reviewed the history of tooth abrasion and reported on the inaccuracy involved with cutting and measuring a groove to monitor on teeth. They found working with a radioactive tooth to be quantitatively more accurate.

Mannerberg[36] studied the tooth surface and reported results which have been accepted up to the present by numerous researchers. He studied replications of small scratches on maxillary cuspids in vivo, made by an instrument of known dimensions, and determined depth of the groove trigonometrically from the measured width. He approximated wear at around 1.5μ per year for some individuals.

Vrbic et al.[57] studied enamel loss caused by pumice in a rubber cup, estimating thickness by calcium analysis of the slurry. They found a layer of 3-4μ was removed in 30 seconds.

Facq and Volpe[22] studied toothbrush abrasion of acrylic surfaces of veneer crowns in vivo. Using a brush and toothpaste* they found an abrasion rate of about 25μ per year.

Pameijer and Stallard[47] reported on the difficulties involved with polishing composite restorations. In vitro they found the "matrix finish" or this surface layer of resin without filler particles wore off after 5 minutes of toothbrushing.

Brandt et al.[6] included in a paper on bonding that the remaining adhesive after debonding will abrade at about the same rate as enamel does. They set this rate at approximately 1μ per year.

Jordan et al.[33] reported on resin restorations on incisors 3 years after placement. They found "little, if any, tendency to abrasive wear". With unfilled restoratives they found "evidence of slight wear involving the incisal edge only".

Fitzpatrick and Way[24] found their technique showed a normal abrasive enamel loss of 1.6μ/85 days. This a rate of 6.4μ per year.

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* Ultrabright

Gwinnett and Ceen[29] observed residual resin and reported "some remnants began to wear away with time". They also found sealants to wear, but no quantitation was included. Gorelick et al.[25] agreed that more research is needed to find out about sealant wear. Most previous reports on sealants have to do with adhesive failures[38] and caries reduction[14].

Zachrisson and Arthun[62] felt that the scratches produced by the TC bur of 5μ or so would wear smooth at the rate of 2μ/year. They felt studies should be done to see if residual adhesive would wear off. In an ongoing study, Zachrisson is observing wear in vivo by leaving a thin layer of adhesive on the tooth, then after a period of time acid etching the area for 5 seconds to provide distinguishable contrasts between resin and tooth, and photographing. After 6 months no appreciable change in the shape of the adhesive "islands" has been seen[61].

REPLICATION

Most of the quantitative studies of intraoral wear and abrasion have been done using grooves or holes and attempting to measure their dimensional change over time. Longitudinal studies in vivo eliminate many of the variables which need to be accounted for in making these determinations. The limitations then become a function of the accuracy of the replication and measurement methods.

Mannerberg[36] used a replication technique using a collodion film in solution with amyl acetate and ether which he placed directly on the tooth. He shadowed the replicas with silver and photographed them through a microscope in transmitted light.

Facq and Volpe[22] used a "hot replication technique" using sheets formed from polyamide resin* which they heated and allowed to settle into their impressions. The original impression of the scratch line was taken using a silicone material+. They cut the replicas and measured depths of the grooves from the side with SEM viewing.

Grundy[28] studied changes in amalgam intraorally using a silicone impression material** and pouring up with an epoxy resin++, followed by SEM study. Pameijer and Stallard[46] did a replication study of self-threading pins using silicone+ and epoxy++. Barnes[2] and Brennan et al.[8] also reported the usefulness of similar techniques.

Tronstad and Leidal[55] used a similar technique but used other brands of silicone*+ and epoxy+* to study effects of hand instrumentation of tooth preparations. They found these materials to be accurate, durable, and especially easy to work with.

Condon and Harcourt[17] found a polyether product*** to have "greater ability to reproduce fine detail" than either silicone or polysulfide impression materials, pointing out the possibility of a thinner mix as an advantage. They poured their impressions up with epoxy++ and after separation washed debris from the replicas with ethyl alcohol. They reported that the impression could be used again for additional replicas.

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* Versalon No. 1112 Polyamide Resin, Chemical Division, General Mills, Kankakee, Ill.

\+ Silflo Silicone Impression Material, J. & S. Davis, Ltd., London

** Verone, Davis Schottlander and Davis, London, E.C.I.

++ Araldite, Ciba-Geigy

*+ Xantopren Blue, Unitek Corp., Monrovia, Calif.

+* Stycast 1266, Emerson & Cuming Inc., Dielectric Materials Div., Canton, Mass.

*** Impregum, E.S.P.E., Seefeld, West Germany

Lilienthal[35] reported study of in vivo surface detail of oral tissues with SEM magnifications of 2000 times. He used silicone rubber* with half the recommended amount of soft hardener. This he coated with a resin chosen for its lower viscosity and ability to flow into minute depressions and cracks. He trimmed these replicas with a carborundum disk before removing the impression material. After separation he removed debris with soapy water and a soft brush, then dried, coated, and scanned. He noted the ability to detect white spot lesions in enamel.

Lilienthal further reported less than 1% difference between photographs of the replicas compared to the original material. Using objects of known dimensions, the limit of resolution seemed to be approximately 0.1μ.

DeWet and Ferreira[20] then reported a method to obtain a quick replica. They were studying etched and sealed occlusal surfaces of teeth. While some epoxy resins take 8-24 hours to cure, unfilled BIS-GMA resin+ sets in approximately 3 minutes. This material shows a distinct macroscopic shrinkage as it sets, so SEM measurements were used to determine a 9% shrinkage magnitude. They used silicone* as the impression material stating that the replicas separated cleaner and easier compared to the polyether**. They washed the replicas in alcohol also, but in this case to "remove the sticky, umpolymerized film of resin from the replica surfaces".

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* Xantopren Blue, Unitek Corp., Monrovia, Calif.

\+ Concise Enamel Bond-composite System, 3M Company, St. Paul, Minn.

** Impregum, E.S.P.E., Seefeld, West Germany

The variations of materials in these SEM replication techniques would have definite advantages depending on the experimental design. Marker[37] reported the SEM resolution good down to 1μ or better using either epoxy or BIS-GMA resin as the replica material.

MATERIALS AND METHODS

Six individuals between the ages of 23 and 36 were directly bonded with materials and technique used commonly in normal clinical treatment. This involved a mesh backed bonding pad* and a lightly filled adhesive+. All twelve anterior teeth were bonded in 5 individuals, and in 1 only the maxillary anterior cuspid to cuspid teeth were included, for a total of 66 teeth. The subjects all had excellent oral hygiene and were asked to continue to brush their teeth as they normally would. All volunteers were aware of the purpose of the project, as 5 were orthodontic residents and 1 an assistant in the orthodontic department**.

All teeth were pumiced briefly with fine flour of pumice and bristle brush, then etched for 60 seconds with 37% phosphoric acid. After rinsing and drying thoroughly, sealant+ was placed, followed by placement of bracket and adhesive in the centers of the facial surfaces of the clinical crowns. Bracket ties++ were placed to minimize tissue trauma.

After a waiting period of 7 days the bonding pads were removed by either squeezing the bracket wings together with a Howe plier or if this failed the base itself was crimped away from the adhesive surface with

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* Dyna Bond Pads with Twin Torque Brackets, Unitek Corp., Monrovia, Calif.

\+ Dyna Bond Adhesive, Unitek Corp., Monrovia, Calif.

** University of Oregon Health Sciences Center, Portland, Ore.

++ S-20 Alastiks, Unitek Corp., Monrovia, Calif.

a band splitting plier*. The remaining adhesive edges were very lightly scraped over with a scaler to dislodge any loose fragments, and the teeth were air dried.

Impressions of the anterior teeth were then taken using previously made acrylic custom trays and a silicone impression material+ handled according to manufacturer's specifications (Figure 1). On one individual two impressions of the maxillary and mandibular anterior teeth were taken to establish a check on accuracy of the technique.

All impressions were "boxed" with wax and poured up with a transparent epoxy resin** which was mixed, poured, and left to cure for 8 hours as suggested by the manufacturer. It was found advantageous to let the small mixing bubbles settle out for 5 minutes of the 30 minute pot life before pouring the material into the impression.

After curing, separation of the replicated arch (Figure 2) was done carefully so the impression could be reused if necessary. Each tooth replica was then thinned from the lingual surface with a carborundum disk to approximately 4 mm and split from the arch so all teeth could be placed on a flat surface (Figure 3). It was found helpful to wash the powdered grinding residue off of the replicas with alcohol and a soft brush before mounting on a base.

Wax trays were constructed to hold a thin layer of freshly mixed methylmethacrylate so all the replicas from each individual could be

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* #215 Plier, Dentronix Inc., Ivyland, Penn.

\+ Xantopren Blue, Unitek Corp., Monrovia, Calif.

** Stycast 1266, Emerson & Cuming Inc., Dielectric Materials Div., Canton, Mass.

placed in their intraoral orientation on the tray prior to the acrylic cure. By then removing the wax backing and sides, an easily handled rectangular tray with mounted replicas was obtained for each individual. (Figure 4).

A period of 3 months (94 days in 1 individual, 90 days in all others) was allowed to pass before another set of replicas was made using the same materials and technique. The original custom trays were reused for this subsequent set of impressions.

An attempt was then made to quantitate the thickness of each pad at one point on each tooth and compare it with the thickness at the same point on the 90 day replica. Using transmitted light, each replica was examined under a light microscope* using 25x and 100x magnifications. The smaller mangification was used for orientation and selection of a point close to the edge of the pad. This allowed the smaller microscopic field of the higher magnification to include a portion of the adhesive pad and a portion of the tooth surface.

The top surface of the adhesive pad consisted of small rectangular projections which allowed rapid orientation to a specific point (Figure 5). The shallow depth of field at the higher magnification required a measurable amount of movement of the objective to then refocus down on the interface line made by the bottom edge of the adhesive pad and the tooth surface.

The rectangular patterns remained on the top surfaces after the 90 day period so that reorientation to the same points was possible.

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* Carl Zeiss, Germany

The measurements were done on the 90 day replicas immediately after the original measurement for each tooth to assure that equivalent points were being compared.

The fine focusing knob was calibrated to 100μ of objective movement per revolution, and since all focusing was done through air, the movement of the objective determined by these calibrations was recorded as the actual thickness of adhesive[42]. Each measurement was done twice on each tooth, recorded, and the average was used for statistical evaluation.

Representative photomicrographs were taken to help demonstrate experimental results. It was felt that these photomicrographs would provide a basis for subjective analysis and possibly stimulate ideas for improvement in experimental design.

RESULTS

A check on the accuracy of the microscopic measuring technique itself was done by measuring depth of a series of 5 conical holes punched into samples of the epoxy teeth and repeating measurements over a 15 day period. The resulting standard error of the measure was 3.74μ. This represented only 0.64% of the mean depth of the holes.

The mean thickness of the adhesive pads of the beginning replicas in the 66 areas selected was 250μ, with a range of 55-930μ. Using the double measurements taken, a standard error of the measure was computed to be 6.36μ. The difference between this and the previous figure was explained in that selection of points from which to measure on the adhesive pads was not as well defined as was possible on the punched holes. It was assumed that this 2.5% measurement error was small enough to allow meaningful quantitation.

The standard error of the method was determined by comparing data from the replicas from the two impressions of the same individual taken one immediately after the other. The computed value was 29.19μ.

The raw data for adhesive wear proved to be somewhat confusing, as some of the 90 day measurements were larger than the beginning measurements. Overall mean wear was determined to be 28μ for the 3 month period.

At this point the photomicrographs were resorted to in order to further observe the material. In general, changes of the replicated pads were limited to slight rounding of the originally sharp edges and points left after bracket removal (Figure 5). Some of the adhesive fracture patterns were rounded to the extent that there seemed very little question there had been wear (Figure 6). But even this form of evaluation was subject to some error.

Comparison of the control teeth showed some variation between pairs of replicas which should have been identical. This difference appeared similar in nature to the rounding and smoothing done by the environmental wearing process (Figures 7A and 7B). Nonetheless, the 90 day replica shows more change than this replication error (Figure 7C).

DISCUSSION

In approaching a method for quantitation of adhesive wear, an attempt was made to select materials proven for accuracy and ease of manipulation. Silicone impression material and epoxy resin are well documented to be adequate for replicating intraoral structures of the dimensions with which we are dealing[55,62]. On this basis it was felt that the replicated teeth made for this project contain accurate information as to how much, if any, wear has taken place.

The orthodontic adhesive* used was also considered to be appropriate, as it represented a near average of light and heavily filled adhesives. The base BIS-GMA contains a mixture of hard fillers greater than 1μ and soft fillers with submicron measurements, together making up 30% of the material[54].

A longer period of wear is perhaps the only major change in design which would be essential, to try and allow a greater amount of wear and create more to quantitate. It is the method of quantitation which remains an unsolved problem. Because of the fact that the error of the method was much higher than expected for this experimental design, a critical re-evaluation was done on the entire procedure. It was then realized that the technique could have included a control of the plane in which the surface of the replica was mounted. It was only after all

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* Dynabond Adhesive, Unitek Corp., Monrovia, Calif.

replicas were mounted and measured that an empirical re-measurement between the same two points was done after changing the angle of the acrylic mounting tray on the microscopic stage. Measurement differences as high as 40 were obtained by changing the mounting angle 30°. So in order for measurements to be consistent and accurate, the point on the top of the pad and at the tooth surface would have to be on the same vertical axis.

It was assumed that this was the reason for 1/3 of the final raw data indicating "positive wear". But assuming random tilt angles would occur in both directions and cancel out most of the inaccuracy, the mean wear of 28μ might still be a reasonable estimate.

The fact that wear (28μ) was less than the standard error of the method (29μ) would indicate that wear of the adhesive is insignificant. But since the quantitation is subject to questionable validity, the photomicrographs were considered to be more conclusive.

For the purposes of this paper, the results agree with the subjective conclusions noted in the literature review, that there is probably not enough wear to assume adhesive will wear completely away in a reasonable amount of time.

The question then arises as to how much of the adhesive should be removed, and this becomes a matter of judgement and opinion once the effects of selected debonding techniques are known. Although this subject has been included in the literature review and the author's opinion is expressed in the conclusions, it is beyond the scope of this paper to analyze it in detail.

SUMMARY

There is a growing utilization of orthodontic appliances which are bonded directly to the tooth surface using the acid etch technique and resin adhesives. Recent investigations have looked at the effects of the bonding and debonding procedures on the enamel surface.

The process of acid etching will remove approximately 10μ of enamel and create microporosities in an additional 40μ layer. This affected layer will remineralize and return to near the original enamel solubility and appearance in a matter of days in a normal environment. The process by which this occurs is not well understood, but uptake of remineralized material is enhanced by fluoride.

The adhesive bond is obtained mechanically by the penetration of resin into the etched microporosities. The resulting multiple tags are in diameter near the size of enamel prisms, or 5-6μ, and probably vary in length from 20 to 50μ.

Most bonding is done with the BIS-GMA adhesives which are diacrylate resins and have superior properties as intraoral adhesives to methyl-methacrylate which is an acrylic resin. Both are presently used for orthodontic bonding, but the cross linking nature of diacrylates results in a material with greater strength, lower water absorption, and less polymerization shrinkage. The strength of the BIS-GMA resin is increased even more by the addition of inorganic fillers.

Clinically, the filled adhesives seem to form a stronger bond, directly related to the amount of filler. As the filler content increases, removal of the adhesives also becomes increasingly difficult. There is clearly a dilemma in finding a strong adhesive which will not be too adherent.

Sealing the freshly etched enamel surface with diluted BIS-GMA resin before placing filled adhesive may impart strength to the bond in that the material may adapt to the etched surface better. But in heavily filled adhesives where the filler particles are larger than the tag widths, intermediary BIS-GMA flows into the etched spaces and inherent resin strength apparently increases overall bond strength.

Sealants may protect the enamel surface from decalcification and also may make removal of heavily filled adhesives easier, but oxygen inhibition of polymerization in sealants currently available often results in weaker bonds and unsealed areas. Wearing off of this unfilled resin is thought to occur but rate of wear remains uncertain.

Removal of adhesive is accomplished with multiple techniques, all of which cause damage to the enamel surface to varying extents. Some of the techniques do restore a normal appearing tooth surface if final pumicing is done.

This paper has attempted to review the concerns for bonded tooth surfaces and has proposed one method of quantitation for residual adhesive wear. A reliable measurement method was not found, but subjective evaluation of adhesive after 90 days in vivo shows evidence of slight wear.

CONCLUSIONS

In order to set standards for a universally acceptable debonding technique, there is a need to agree on definitions of "normal tooth surface", "polished surface", and "high speed" or "low speed" in terms of rpm.

With the findings and definitions currently available, and in consideration of surface enamel, it seems appropriate to suggest that instrumentation for removal of orthodontic adhesive which is in contact with enamel be kept to a minimum. Since there appears to be some wear of the material, the ideal might well be to leave a thin layer of several microns of solid adhesive and allow natural wear to expose the enamel and adhesive tag junction.

Since heavily filled composite surfaces collect plaque more readily than smooth enamel, it would be best to use a light or medium filled adhesive. This would provide adequate bond strength, the bulk removal would be less difficult, and the surface could be polished smoother.

Resin tags in the enamel surface do not appear to change plaque pattern, do not increase the solubility of the involved enamel, are not prone to leakage or staining, and are not an esthetic problem. So it seems justified to leave some residual adhesive for the sake of preserving tooth structure and simply polishing with pumice in a rubber cup to achieve a natural looking enamel surface. This would come as close to restoring the original surface as practical.

Although the debonding techniques using the green rubber wheel or sandpaper disks can restore a natural looking surface, the tungsten carbide bur at slow speed seems to be the most appropriate and least harmful instrument reported to date.

Regardless of debonding technique, extreme care should be taken even during bulk removal of residual resin. The resulting surface should be left polished, and use of fluoride should be encouraged before, during, and after the use of orthodontic bonded appliances.

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Figure 1: Silicone impression of maxillary anterior teeth with orthodontic adhesive left on the enamel surface after removal of bonding pad.

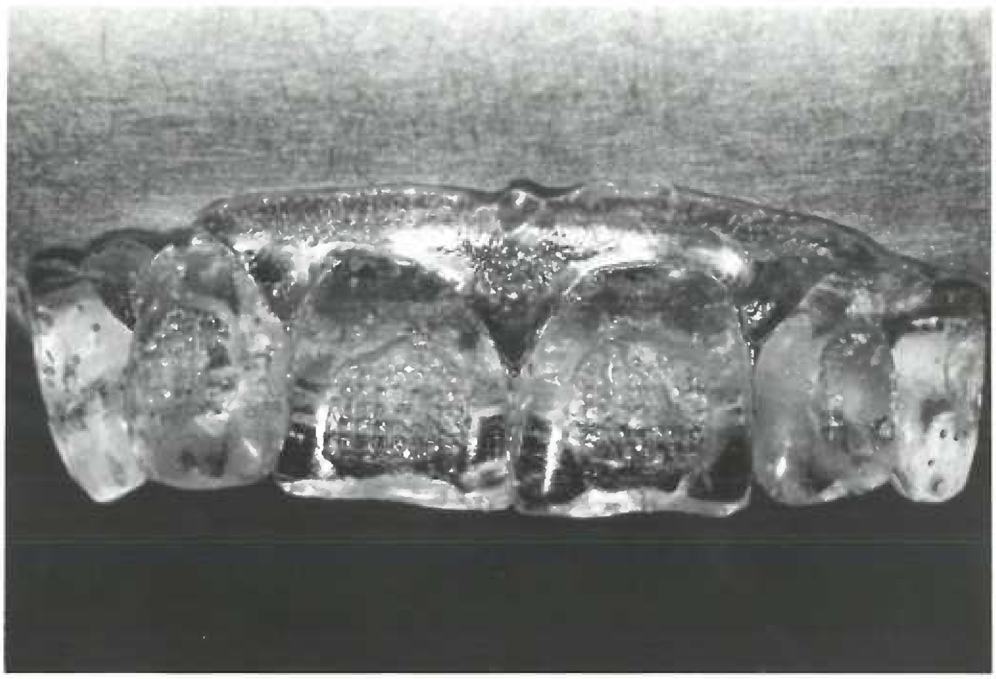

Figure 2: Epoxy resin replica of maxillary anterior teeth immediately after separation following an 8-hour cure in the silicone impression.

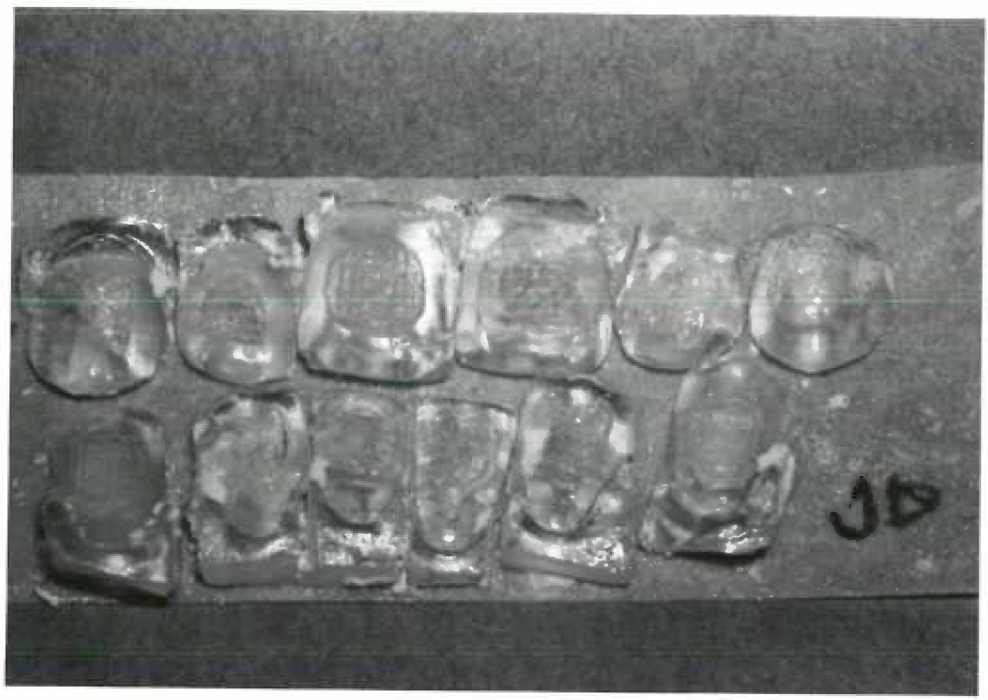

Figure 3: Individual tooth replicas after reduction of the lingual bulk and fracturing at contact points.

Figure 4: Replicas from one individual mounted in acrylic. Top mounting tray is at start of the observation period and bottom tray is 90 days later.

Figure 5A

Figure 5B

Figure 5: Photomicrographs of a replicated adhesive pad on a maxillary central incisor. 5A is at start and 5B is 90 days later.

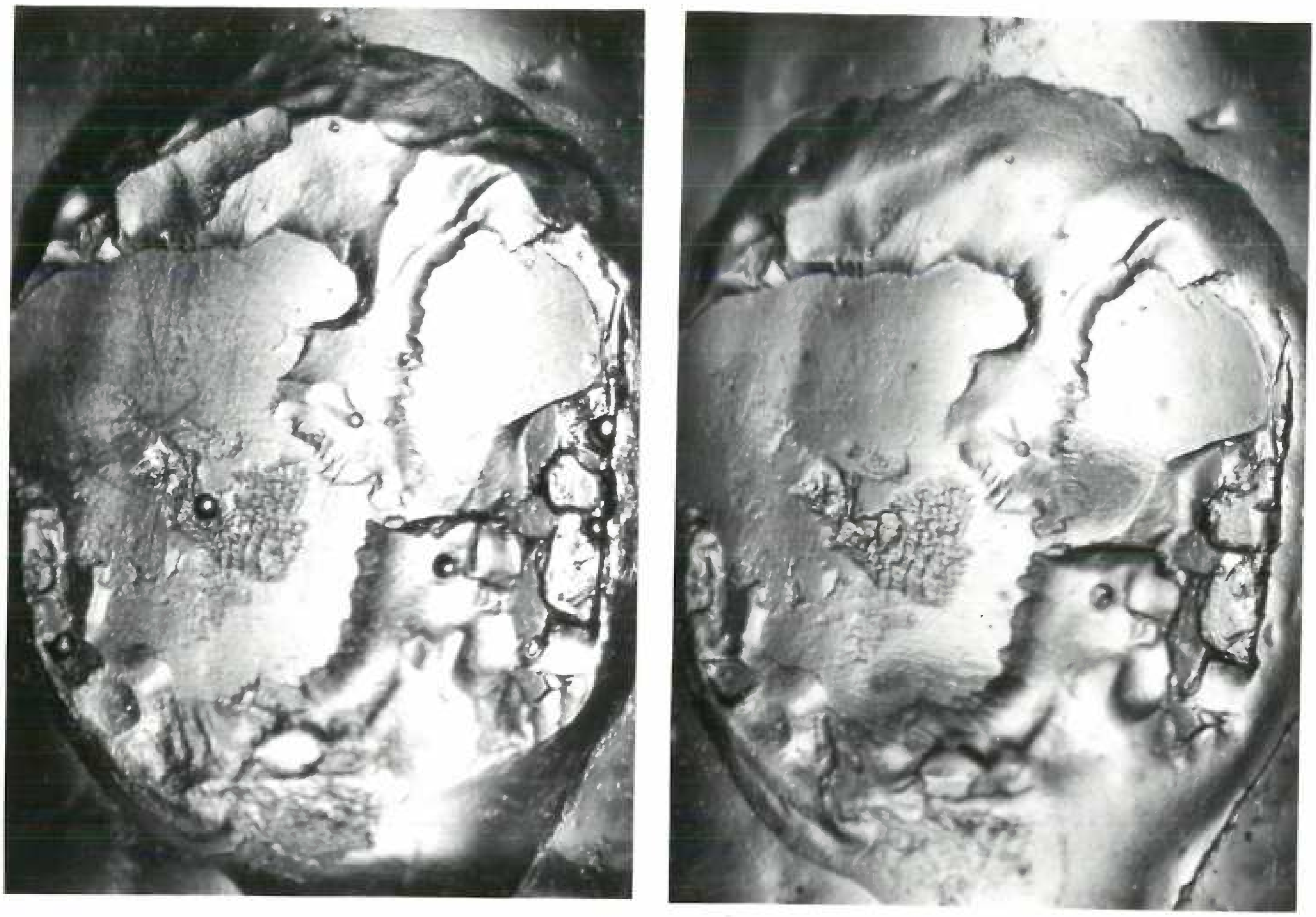

Figure 6A

Figure 6B

Figure 6: Photomicrographs of a replicated mandibular right cuspid at start (6A) and 94 days later (6B). At the time of bracket removal most of the adhesive fractured off the tooth.

Figure 7A

Figure 7B

Figure 7: Photomicrographs of a replicated adhesive pad left on a mandibular cuspid. 7A and 7B are made from two different impressions of the same tooth at start and 7C is the same pad 90 days later.

Figure 7C