WEIGHT LOSS OF ORTHODONTIC BONDING RESINS IN ORGANIC SOLVENTS

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INTRODUCTION

It is now commonplace to bond metal orthodontic brackets with open mesh bases directly to etched tooth enamel, with either polymethyl methacrylate (PMMA) resin or bisphenol A glycidyl dimethacrylate (BIS-GMA) resin.

This approach is a development from work by Buonocore (1955), who showed that PMMA resin could be firmly secured to an enamel surface, if it was first treated with dilute phosphoric acid, then washed and thoroughly dried. The acid-etch technique was later used to bond orthodontic brackets to enamel with PMMA resin (Swanson and Beck, 1960).

In orthodontics, the direct-bonding procedure has gained wide acceptance (Gorelick, 1979) and has numerous advantages, including ease and precision of bracket placement, improved patient comfort and enhanced aesthetics (Zachrisson, 1985).

As the manufacture of brackets increases in precision and the design of the brackets becomes more complex (Wright and Powers, 1985), cost factors are now receiving more consideration. Consequently, there appears to be an increasing interest in the re-use of some brackets. Also situations can arise when a patient is temporarily under another orthodontist's care, where it is necessary to rebond an existing bracket because an identical new bracket is not available.

A number of commercial organisations now offer various processes which recycle used metallic direct-bond brackets. The procedures employed remove any residual bonding resin from the mesh base of a bracket, and in instances where the process causes some tarnish of the bracket surface, a polishing step is included as part of the recycling process (Buchman, 1980; Vlock, 1981).

As far as can be determined from the literature, the recycling procedures essentially fall into one of two categories. In one, the bracket is exposed to temperatures in the range 800° to 850°F (427° to 454°C) to remove the residual bonding resin by controlled burning. The bracket is then subject to electropolishing (Buchman, 1980; Vlock, 1981; Wheeler and Ackerman, 1983). The second procedure uses unspecified chemicals to dissolve the resin remnants (Buchman, 1980; Hixson *et al.*, 1982; Mascia and Chen, 1982). None of the companies using the above procedures* have released exact details of the techniques or materials employed, in either the published literature or in response to personal communications from the author.

One of the potential disadvantages of the heat-based procedures is that the metallurgical properties, in particular the resistance to corrosion, may be compromised (Buchman, 1980). In the oral cavity, corrosion has been implicated as a possible causative factor in the staining of enamel adjacent to the periphery of some brackets (Ceen and Gwinnett, 1980; Gwinnett, 1982; Maijer and Smith, 1982).

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* These include: Esmadent, Highland Park, Illinois, U.S.A.; Orthocycle Company, St. Louis, Missouri, U.S.A.; Orthotronics Incorporated, Gloversville, New York, U.S.A.; Vector Dental Corporation, Arcadia, California, U.S.A.

In contrast to the results with heat-treated brackets, Buchman (1980) found no alterations in the metallurgical properties of brackets recycled using a chemically-based procedure.

The potential advantages of a chemically-based approach and the lack of published data on the process are such that further study of the subject is warranted.

It is well established that PMMA resins have the potential to be degraded by a number of organic solvents (Fuchs and Suhr, 1975; ASTM* D 2857 - 70; Boyer and Chalkley, 1982). However, apart from some preliminary work with a few selected organic solvents by Wu and McKinney (1982; 1985), little is known about the corresponding situation with BIS-GMA resins. In view of the current overwhelming popularity of BIS-GMA resins as orthodontic bonding agents and the increasing interest in the recycling of metallic direct-bond orthodontic brackets, more data on the breakdown of BIS-GMA resins in organic solvents is indicated.

This *in vitro* study was undertaken to determine the effect of four common organic solvents, benzene, chloroform, ethyl alcohol and isobutyl alcohol on the weight loss of PMMA and BIS-GMA orthodontic bonding resins attached to the mesh base of metallic direct-bond orthodontic brackets.

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* American Society for Testing and Materials.

REVIEW OF LITERATURE

History of Bonding

In 1955, Buonocore demonstrated that pretreatment of the enamel surface with 85 per cent phosphoric acid, increased the adhesion of acrylic resin materials. The introduction of the acid-etch bonding technique has since led to many changes in the practice of dentistry.

Bonding of orthodontic attachments using the acid-etch technique was reported in the early 1960s (Swanson and Beck, 1960; Newman, 1965). At first, plastic brackets were bonded to the tooth surface (Newman *et al.*, 1968; Newman, 1969; Newman, 1971) with a PMMA (polymethyl methacrylate) resin. In a further development, Miura *et al.*, (1971) incorporated a tri-n-butyl borane catalyst in PMMA resin. It was claimed that this catalyst system allowed the material to polymerise with no shrinkage, even under slightly wet conditions.

Orthodontic bonding resins based on BIS-GMA (bisphenol A glycidyl dimethacrylate) were also investigated (Silverman *et al.*, 1972; Reynolds and von Fraunhofer, 1976b; Gorelick, 1977). A significant improvement in bracket retention was achieved, when a BIS-GMA orthodontic bonding resin was used (Zachrisson, 1977).

Orthodontic brackets are generally plastic, ceramic or metal (Fields, 1982; Zachrisson, 1985). Metal brackets are the most popular (Gorelick, 1979), relying on mechanical retention for bonding. When first developed, perforations were made in metal banding material, but these have more recently been replaced by foil mesh bases welded or brazed to brackets (Mizrahi and Smith, 1971; Brandt *et al.*, 1975; Zachrisson and Brobakken, 1978). Improvements in bracket base design have also increased the bond strength of metal orthodontic brackets (Reynolds and von Fraunhofer, 1976a; Lopez, 1980; Maijer and Smith, 1981; Smith and Maijer, 1983).

Orthodontic Bonding Resins

In the twenty years since the introduction of orthodontic bonding, only two basic types of resin, polymethyl methacrylate (PMMA) and bisphenol A glycidyl dimethacrylate (BIS-GMA), have been used to attach brackets to etched enamel.

A review of the orthodontic bonding resins commercially available in Britain in the 1970s (Reynolds, 1975) showed that approximately half were PMMA-based and the remainder were either unfilled or filled BIS-GMA resins. Many of the BIS-GMA-based materials were either pit and fissure sealants or composite restoratives.

Currently there is a trend away from the PMMA resins to the BIS-GMA resins (Gorelick, 1979). The principal reason is that reduced bond strengths have been reported with PMMA resins as compared to BIS-GMA orthodontic bonding resins (Faust *et al.*, 1978). Resins with large particle fillers are recommended for extra bond strength (Buzzitta *et al.*, 1982) but may contribute to more plaque accumulation around the periphery of a bracket (Zachrisson and Brobakken, 1978).

Damage to the enamel surface is possible with current debonding techniques. Deep scratches on the tooth surface (Retief and Denys, 1979) and a significant loss of enamel have been reported (Diedrich, 1981). The amount of surface enamel lost during debonding procedures has been reported to be higher with BIS-GMA orthodontic bonding resins than with PMMA resins (Brown and Way, 1978). A similar trend to increased enamel loss was observed with higher filler loadings (Pus and Way, 1980).

(a) PMMA Resin

PMMA resin is derived from the monomer methyl methacrylate whose formula is $CH_2{=}C(CH_3){-}COOCH_3$ (Greener *et al.*, 1972; Phillips, 1982). Most commercial preparations consist of two components, the monomer, which is usually a colourless liquid, and the polymer, which consists of particles of polymerised methyl methacrylate. When the monomer and polymer are combined in the appropriate proportions, a long-chain structure with little or no cross-linking is formed. An idealised version of the structure of polymerised PMMA resin is shown in Figure 1 (Lee, 1966).

The PMMA resins used as orthodontic bonding agents consist of a polymer and monomer, with some being activated by a tertiary amine-benzoyl peroxide system (Newman *et al.*, 1968; Council on Dental Materials, Instruments, and Equipment, 1982; Maijer, 1982; Zachrisson, 1985). However, Miura *et al.*, (1971) used a tri-n-butyl borane derivative to activate a PMMA orthodontic resin.

PMMA resins used in orthodontic bonding can be either filled or unfilled. One of the purposes of the filler is to reduce polymerisation

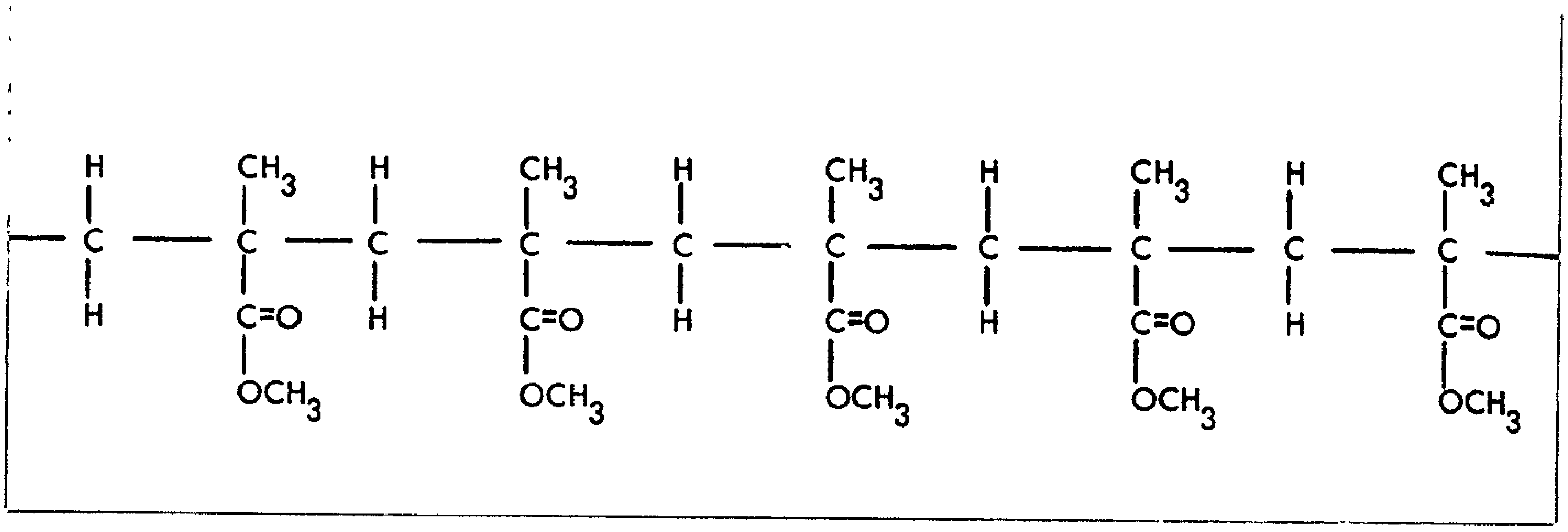

Figure 1

Idealised structure of polymerised PMMA resin.

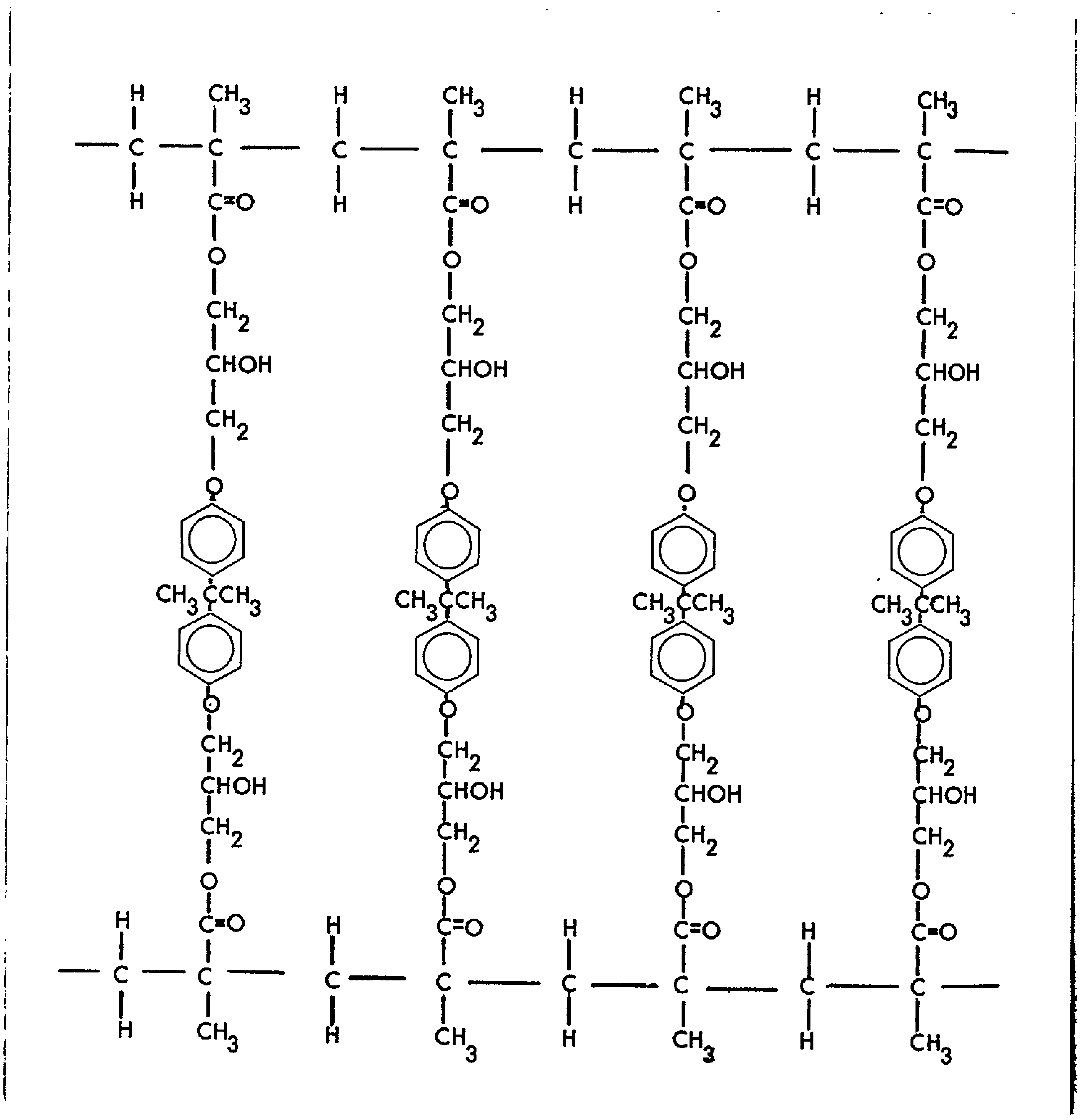

Figure 2

Idealised structure of polymerised BIS-GMA resin.

shrinkage and the coefficient of thermal expansion (Greener *et al.*, 1972).

(b) BIS-GMA Resin

Since its development in the early 1960s (Bowen, 1963), BIS-GMA resin has been widely used as the resin component of composite restorative resins, pit and fissure sealants and orthodontic bonding resins (Council on Dental Materials and Devices, 1975; Bowen, 1982). Unlike PMMA resin, BIS-GMA resin is highly cross-linked which helps give the polymerised resin, strength and rigidity (Phillips, 1982). An idealised structure of polymerised BIS-GMA resin is shown in Figure 2 (Lee, 1966).

Because the resin is extremely viscous, monomers such as glycol methacrylate or methyl methacrylate (Greener *et al.*, 1972; Maijer, 1982) can be used to thin the mixture to a suitable consistency. The monomers used as diluents are rapidly incorporated into the cross-linked structure during polymerisation (Craig, 1985).

Various systems can be used to initiate polymerisation of BIS-GMA resins including those that use ultra-violet light (364-367 nm wavelength) or visible light (440-480 nm wavelength) (Rock, 1974; Tavas and Watts, 1979; Read, 1984; Tavas and Watts, 1984). However, as far as can be ascertained from the literature, most of the currently used BIS-GMA-based orthodontic bonding resins are polymerised using the traditional tertiary amine-benzoyl peroxide, initiator-catalyst system (Reynolds, 1975; Reynolds and von Fraunhofer, 1976b; Maijer, 1982).

Maijer (1982) in a review of BIS-GMA-based orthodontic bonding resins reported that all the commercial products examined had filler loadings ranging from 24 to 72 per cent by weight. These fillers, which can include borosilicate glass powder or silica glass powder, help reduce the polymerisation shrinkage and coefficient of thermal expansion of the resin.

A recent development has been the introduction of bonding resins that require no mixing. These materials set when a layer of primer fluid, placed on the etched enamel surface and on the mesh base of the orthodontic bracket, are brought into contact with a layer of resin "sandwiched" between the tooth and the bracket. The bracket can be positioned before polymerisation occurs some 30 to 60 seconds later (Belostoky, 1982; Zachrisson, 1985).

No long-term studies are yet available on these "no-mix" bonding resins. Little is known about the proportion of unreacted monomer that remains in the cured material (Thompson *et al.*, 1982).

Techniques for Removal of Bonding Resins from Orthodontic Brackets

In situations where metallic direct-bond orthodontic brackets have been selected for re-use, various techniques have been employed to either partially or completely remove any residual bonding resin attached to the mesh base.

(a) Partial Removal

Wright and Powers (1985) used a green stone in a handpiece to trim the remaining bonding resin to the level of the outer surface of the mesh base. When the treated brackets were bonded, *in vitro,* to plastic cylinders, it was found that the tensile bond strength ranged from approximately 50 per cent to almost 97 per cent of that obtained with new unused brackets. Only BIS-GMA-based bonding resins were assessed.

(b) Complete Removal

(i) *Use of Heat*

A number of commercial organisations now offer a service which essentially involves the removal of residual bonding resin by controlled burning.* This in turn can be followed by a short period of electropolishing, to remove the tarnished oxidised layer from the surfaces of the bracket.

Little published data were found that describe the controlled burning process. It appears that the temperatures used do not exceed 800° to 850°F (427° to 454°C) (Vlock, 1981; Wheeler and Ackerman, 1983).

There is some question as to whether the heating process has an

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* These include: Esmadent, Highland Park, Illinois, U.S.A.; Orthotronics Incorporated, Gloversville, New York, U.S.A.; Vector Dental Corporation, Arcadia, California, U.S.A.

adverse effect on the metallurgical properties of the bracket. Buchman (1980) reported a loss of ferromagnetism in brackets recycled by one commercial organisation, but not in brackets recycled by another organisation, even though both companies used a controlled burning procedure.

Theoretically, metallurgical transformations can begin to occur in the types of stainless steel used in orthodontic brackets*, at the temperatures (800° to 850°F) used in the heat-based recycling processes (Sutow and Pollack, 1981; Phillips, 1982). At these temperatures, carbon, which makes up 0.03 to 0.15 per cent of the stainless steel commonly used in orthodontic brackets (Williams, 1982; American Society for Metals, 1983), can start to precipitate at the grain boundaries (Phillips, 1982). This may lead to stress-relieving or softening of cold worked metal as well as a decreased resistance to corrosion (Buchman, 1980). In this respect, it is noteworthy that corrosion at the margins of metallic direct-bond orthodontic brackets has been cited as being a factor in tooth discolouration associated with the use of these brackets (Ceen and Gwinnett, 1980; Gwinnett, 1982; Maijer and Smith, 1982). All reported stains were in the green to black colour range and an area of resin deficiency was always noted adjacent to the stained area.

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* For example: Stainless Steel Types 303, 304, 304L, 316 and 316L. One or more of these types of stainless steel are used in orthodontic brackets manufactured by Ormco, Glendora, California, U.S.A.; Rocky Mountain/Orthodontics, Denver, Colorado, U.S.A.; TP Laboratories Incorporated, La Porte, Indiana, U.S.A.; and the Unitek Corporation, Monrovia, California, U.S.A. (personal communications).

The electropolishing procedure that can be used to remove the tarnished, oxidised layer remaining after the heating process, has been shown to cause some loss of metal from the mesh base (Mascia and Chen, 1982). In contrast, studies measuring the bracket slot following controlled burning of the resin and subsequent electropolishing (Buchman, 1980; Hixson *et al.*, 1982) indicate no significant change in dimension and associated metal loss.

The bonding properties of brackets re-used after a heat-based reconditioning process have been assessed by several workers. Wheeler and Ackerman (1983) found a 6 per cent reduction in the tensile strength of brackets bonded *in vitro* to human enamel after the recycling process. Similarly, Wright and Powers (1985) found reductions in tensile strength ranging from zero to just over 50 per cent for recycled brackets bonded *in vitro* to plastic cylinders. In contrast McClea and Wallbridge (1986) found no significant differences in the tensile and shear strengths of recycled or new brackets. The test procedure used by McClea and Wallbridge (1986) differed from those used by other workers, in that the brackets were not bonded to teeth or plastic cylinders, but were bonded to each other, mesh surface to mesh surface, using a BIS-GMA resin.

(ii) *Use of Chemicals*

As far as can be determined from the literature, only one commercial organisation* uses a chemical process to remove

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* Orthocycle Company, St. Louis, Missouri, U.S.A.

residual resin from used metallic direct-bond orthodontic brackets (Buchman, 1980; Hixson *et al.*, 1982; Mascia and Chen, 1982; Wright and Powers, 1985). However, no data were found which indicate the type of chemical or combination of chemicals used, or the process followed.

Buchman (1980) found that in contrast to a heat-based procedure, chemical removal of bonding resin caused no alterations in the metallurgical properties of the bracket.

Wright and Powers (1985) found no significant differences in the bonding properties of used brackets treated with either a heat-based or chemically-based recycling process. In general, the tensile strength of chemically reconditioned brackets bonded *in vitro* to plastic cylinders was 30 per cent to 50 per cent less than that obtained with new unused brackets. Similarly, Mascia and Chen (1982) found comparable bond strengths for brackets recycled using either heat-based or chemically-based processes. Hixson *et al.*, (1982) found no statistically significant change in bracket slot dimension following a chemically-based reconditioning process.

Resin Degradation in Organic Solvents

The degradation of a resin in an organic solvent is a slow process that occurs in two stages (Billmeyer, 1971). Initially, the solvent molecules diffuse into the resin to produce a swollen gel. In the second stage, the gel gradually disintegrates. This dissolution process may be accelerated by agitation.

Materials that are highly cross-linked or have strong hydrogen bonding may only proceed through the first stage of breakdown to gel formation. Other factors apart, the higher the molecular weight of a resin, the slower is the rate of dissolution (Billmeyer, 1971).

Resins may not only be broken down by organic solvents, but by other agents such as heat, mechanical energy, electromagnetic radiation (e.g., gamma rays, x-rays and ultra-violet light), ultrasonics and enzymatic catalysed hydrolysis (Gilding, 1981).

The solubility of a resin in a solvent is very dependent upon the similarity of its solubility parameter with that of the solvent (ASTM D 3132 - 84; Burrell, 1970). In essence, the solubility parameter is a complex unit of measurement which reflects the energy with which the molecules of a given volume of substance are held together (Gardon, 1965).

There are many organic solvents whose solubility parameters fall within the range of those for PMMA resin (Burrell, 1975) and BIS-GMA resin (Wu and McKinney, 1982). For PMMA resin the list includes acetone, benzene, chloroform, dibutyl phthalate, ethyl alcohol, ethylene dichloride, isobutyl alcohol and triethylene tetramine (Fuchs and Suhr, 1975; ASTM D 2857 - 70; Weast and Astle, 1981; Boyer and Chalkley, 1982). While for BIS-GMA resin the list includes acrolein, benzene, chloroform, ethyl alcohol, formylpiperidine, isobutyl alcohol, pentachloroethane and valeronitrile (Burrell, 1975; Wu and McKinney, 1982; McKinney and Wu, 1985). It is noteworthy that several readily available solvents such as benzene, chloroform, ethyl alcohol and isobutyl alcohol are common to both lists.

Wu and McKinney (1982; 1985) have reported that 2 weeks immersion of BIS-GMA resin in heptane or ethyl alcohol, produced a discernible softening of the surface of the material. Furthermore, Asmussen (1984) has shown that the type of diluent used with BIS-GMA resin can have a marked effect on the resistance of the resin surface to softening in ethyl alcohol, acetic acid, propionic acid, or lactic acid. In addition, Asmussen (1982a) showed that the more unreacted double bonds in polymerised BIS-GMA resin, the greater the likelihood of reduced surface hardness.

MATERIALS AND METHODS

MATERIALS

Orthodontic Bonding Resins

Two commercially available orthodontic bonding resins were used (Figures 3 and 4). The PMMA resin was *Orthomite Super-Bond** (Sun Medical Co., Ltd, Kyoto, Japan; Batch numbers 30601 and 41001) and the BIS-GMA resin was *Monolok*** (Rocky Mountain/Orthodontics, Denver, Colorado, U.S.A.; Batch numbers 081083 [adhesive paste] and 041884 [liquid primer]).

Orthodontic Brackets

Edgewise triple control brackets for upper right central incisors with a 'Lok-Mesh' bonding base brazed to the brackets were employed (Rocky Mountain/Orthodontics, Denver, Colorado, U.S.A.; Bracket number A-5756 and 'Lok Mesh' bonding base D-2205).

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* Composition of *Orthomite Super-Bond* (Miura, 1986).

** Composition of *Monolok* (Wright and Powers, 1985).

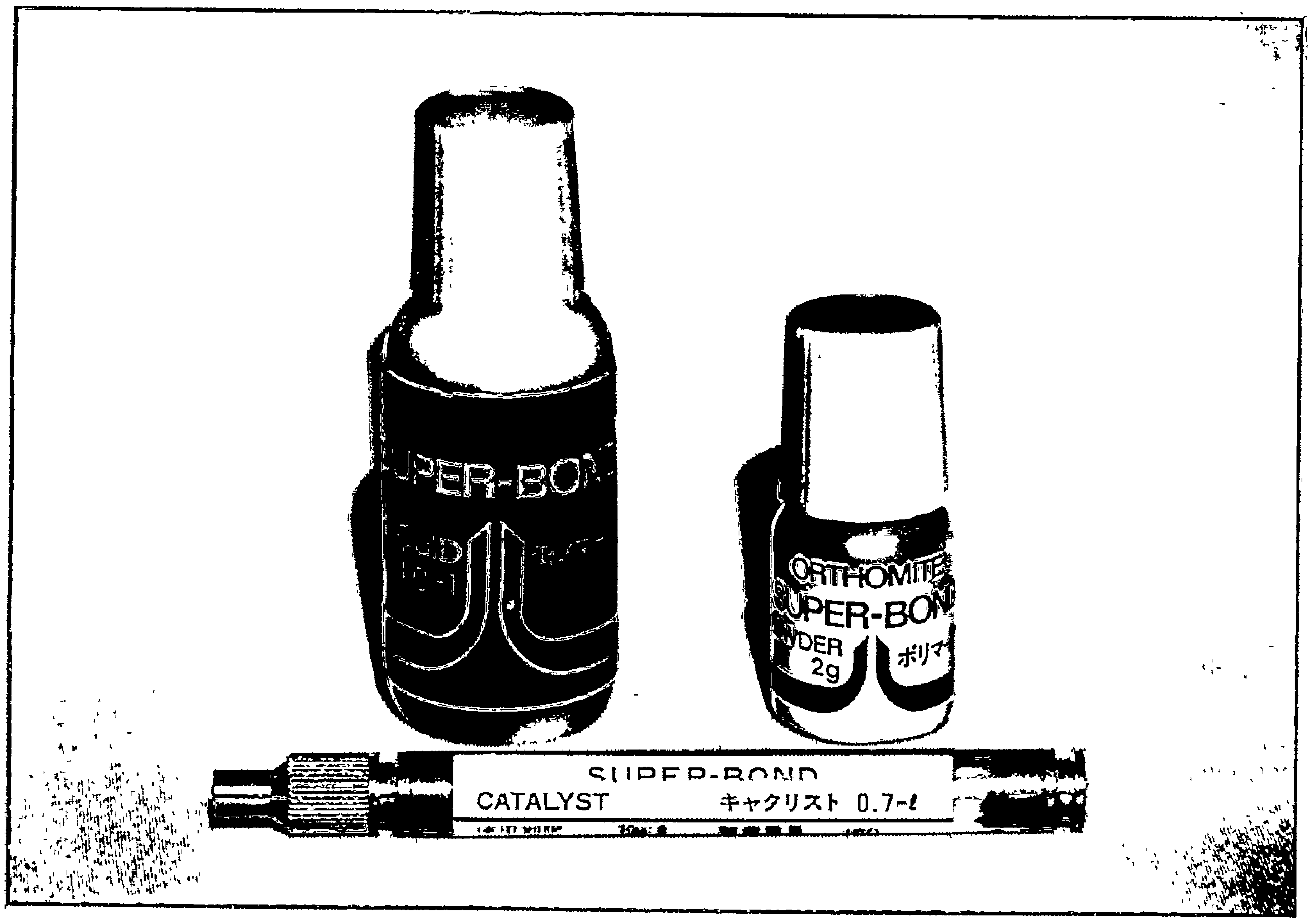

Figure 3

Orthomite Super-Bond brand of orthodontic bonding resin.

Figure 4

Monolok brand of orthodontic bonding resin.

Solvents

Four readily available organic solvents with solubility parameters within the range of those for PMMA resin (Burrell, 1975) and BIS-GMA resin (Wu and McKinney, 1982), were selected. Analytical reagent grade organic solvents were used throughout the study: benzene (Ajax Chemicals, Sydney, N.S.W., Australia; Batch number 210191); chloroform (May and Baker Australia Pty Ltd, West Footscray, Vic., Australia; Batch number 40748); ethyl alcohol (Ajax Chemicals, Sydney, N.S.W., Australia; Batch number 402153); and isobutyl alcohol (Ajax Chemicals, Sydney, N.S.W., Australia; Batch number 53102). The solubility parameters for benzene, chloroform, ethyl alcohol and isobutyl alcohol are 18.8, 19.0, 26.0 and 21.5 $[J/m^3]^{\frac{1}{2}} .10^{-3}$ respectively (Burrell, 1975).

Apparatus

Specimens were stored in 50 ml glass bottles with metal screw lids. A Memmert Oven Model 50-80 (Memmert, Schwabach, West Germany) set at 37°C (ASTM D 543 - 67) was used for the storage of specimens during the solvent immersion periods.

Specimens were weighed on a Mettler Balance Type H16 (E. Mettler, Zurich, Switzerland) and a Sanophan Ultrasonic Cleaner Type CX7226 (Ultrasonic Industries Pty Ltd, Sydney, Australia) was used for specimen cleaning after solvent immersion and prior to weighing.

METHODS

Each unbonded bracket as supplied by the manufacturer was initially weighed and then placed in a pair of Dentaurum No. 025-277 Clamping Tweezers (Dentaurum, Pforzheim, West Germany). The mesh surface was covered with either PMMA resin or BIS-GMA resin which had been prepared and applied according to the manufacturer's directions. Each bracket was placed resin surface downwards on a PTFE (polytetrafluoroethylene) surface, under a constant force of 8 oz (227 g) applied via a Dontrix Pressure Gauge (E.T.M. Corporation, Monrovia, California, U.S.A.) for a period of 5 minutes. Excess resin was removed from the periphery of each bracket base before the material had completely polymerised. Each specimen was then left on the PTFE surface for 7 days at room temperature before being removed with E.T.M. No. 155 Bond Removing Pliers (E.T.M. Corporation, Monrovia, California, U.S.A.).

After weighing, each specimen was immersed mesh surface upwards, in 20 ml of solvent in a 50 ml glass container. The container was sealed and placed in an incubator at 37°C. Although the total immersion periods were 2 weeks, 4 weeks and 6 weeks, each specimen was placed in fresh solvent every 7 days. All solvents were handled using recommended safety procedures (Marsden, 1963).

At the end of either 2 weeks, 4 weeks or 6 weeks, each specimen was removed from the appropriate solvent, held in a pair of Dentaurum Clamping Tweezers and cleaned with a bur brush. The specimen was re-immersed in new solvent in a glass container which was placed in an ultrasonic cleaner for 10 minutes.

The final weight of each specimen was determined after it had been allowed to air dry for 7 days, under cover, at room temperature.

Weighing Precision

The precision of the weighing method was determined by re-weighing 3 brackets selected at random. Each bracket was weighed 6 times. In no instance did the coefficient of variation exceed 0.06 per cent, the values being 0.06 per cent (1st bracket), 0.04 per cent (2nd bracket) and 0.06 per cent (3rd bracket).

Statistical Analysis

Comparisons of the mean weight loss of the specimens in the different solvents at 2 weeks, 4 weeks and 6 weeks were made using Duncan's new multiple-range test (Steel and Torrie, 1960). The same procedure was used to determine the effect of immersion period on the weight loss of specimens in each solvent. Comparisons between means were at the 0.05 level of significance.

Scanning Electron Microscopy

Representative 6-week specimens from each solvent treatment group were examined using scanning electron microscopy. Each specimen was mounted on an aluminium stub and the resin surface sputter coated with gold in a Dynavac Sputter Coater Model SC 150 (Dynavac, Melbourne, Vic., Australia).

The specimens were examined in a scanning electron microscope (Stereoscan 600, Cambridge Scientific Instruments, Cambridge, England) at an accelerating voltage of 7.5 kV.

RESULTS

Unbonded Brackets*

There was negligible variation in the weight of the unbonded brackets as supplied by the manufacturer. The mean weight of 10 of the brackets selected at random was 85.98 mg (S.D. 0.61). A scanning electron microscope examination of the mesh surface of an unbonded bracket showed no evidence of extraneous deposits (Figures 5A and 5B).

None of the test solvents had any appreciable effect on the weight of unbonded brackets during an immersion period of 6 weeks (Table 1).

PMMA Resin

Presented in Tables 2 to 4 are data on the weight loss of PMMA resin in the test solvents at each of the three time intervals (2 weeks, 4 weeks and 6 weeks).

The findings in terms of mean percentage weight loss are summarised in the histogram shown in Figure 6.

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* Throughout this thesis the term unbonded bracket refers to the basic bracket as supplied by the manufacturer.

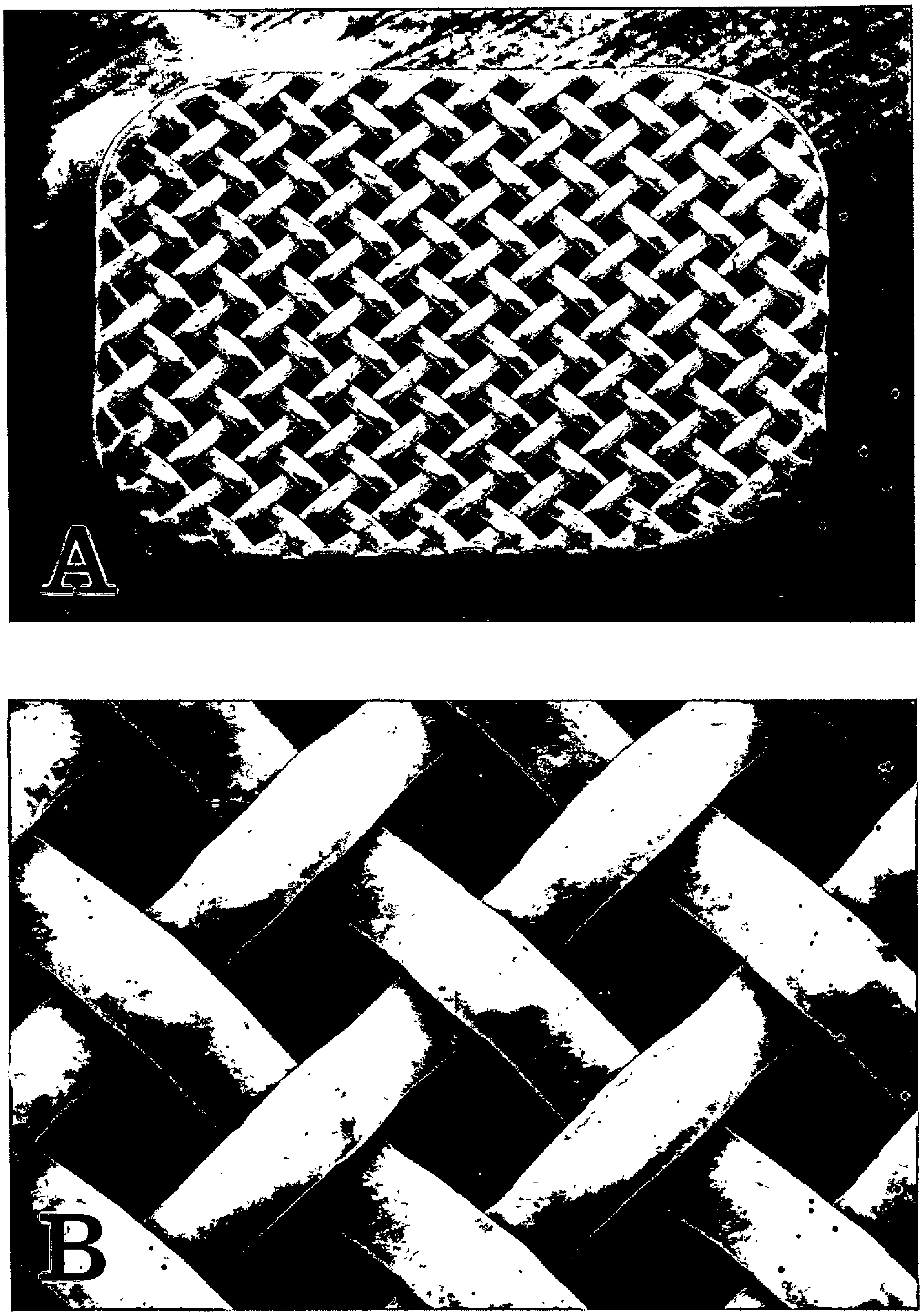

Figure 5

Scanning electron micrographs of the mesh surface of an unbonded bracket prior to the application of bonding resin. A, Low power view. (Original magnification x10.) B, Higher power view. (Original magnification x60.) In both micrographs there is no evidence of extraneous surface deposits.

Table 1

Effect of test solvents on weight of unbonded brackets after a 6-week immersion period*

Solvent	Number of specimens	Mean weight (mg) Initial	(S.D.)	Final	(S.D.)	Difference
Benzene	6	85.98	(0.96)	85.97	(0.95)	NS**
Chloroform	6	85.39	(0.47)	85.40	(0.45)	NS
Ethyl alcohol	6	85.58	(0.33)	85.58	(0.31)	NS
Isobutyl alcohol	6	85.82	(0.99)	85.82	(0.96)	NS

* Based on data presented in Appendix 1.

**NS Not significant at 0.05 level.
(Student's *t* test)

Table 2

Weight loss of PMMA resin following 2 weeks immersion in test solvents

Solvent		Specimens							
		1	2	3	4	5	6	Mean	(S.D.)*
Benzene	Initial weight (mg)	5.70	6.35	5.20	4.75	6.25	7.60		
	Final weight (mg)	0.65	0.95	0.60	0.40	0.70	1.35		
	% Resin loss	88.6	85.0	88.5	91.6	88.8	82.2	87.5	(3.3)
Chloroform	Initial weight (mg)	6.10	7.20	6.75	8.20	7.55	8.10		
	Final weight (mg)	0.40	0.45	0.55	0.95	0.75	1.45		
	% Resin loss	93.4	93.8	91.9	88.4	90.1	82.1	90.0	(4.3)
Ethyl alcohol	Initial weight (mg)	6.95	7.20	5.20	5.60	5.20	7.40		
	Final weight (mg)	5.00	4.60	3.10	3.30	3.40	4.05		
	% Resin loss	28.1	36.1	40.4	41.1	34.6	45.3	37.6	(6.0)
Isobutyl alcohol	Initial weight (mg)	6.70	4.35	6.95	5.45	7.30	6.20		
	Final weight (mg)	6.30	3.15	5.65	4.95	6.25	6.10		
	% Resin loss	6.0	27.6	18.7	9.2	14.4	1.6	12.9	(9.4)

* Differences between the following mean values are significant at the 0.05 level: benzene v ethyl alcohol; benzene v isobutyl alcohol; chloroform v ethyl alcohol; chloroform v isobutyl alcohol; ethyl alcohol v isobutyl alcohol (Duncan's new multiple-range test).

Table 3

Weight loss of PMMA resin following 4 weeks immersion in test solvents

Solvent		Specimens							
		1	2	3	4	5	6	Mean	(S.D.)*
Benzene	Initial weight (mg)	7.85	6.95	6.55	7.95	7.30	6.40		
	Final weight (mg)	0.30	0.15	0.00	0.00	0.30	0.25		
	% Resin loss	96.2	97.8	100.0	100.0	95.9	96.1	97.7	(1.9)
Chloroform	Initial weight (mg)	7.55	8.05	6.85	8.35	8.20	7.85		
	Final weight (mg)	0.10	0.15	0.00	0.00	0.20	0.00		
	% Resin loss	98.7	98.1	100.0	100.0	97.6	100.0	99.1	(1.1)
Ethyl alcohol	Initial weight (mg)	9.30	8.25	6.00	7.10	8.05	8.10		
	Final weight (mg)	8.20	6.00	4.55	3.00	5.85	5.75		
	% Resin loss	11.8	27.3	24.2	57.8	27.3	29.0	29.6	(15.2)
Isobutyl alcohol	Initial weight (mg)	8.20	7.75	8.00	7.10	6.60	6.85		
	Final weight (mg)	7.55	6.90	6.75	5.35	4.15	4.10		
	% Resin loss	7.9	11.0	15.6	24.7	37.1	40.2	22.8	(13.6)

* Differences between the following mean values are significant at the 0.05 level: benzene v ethyl alcohol; benzene v isobutyl alcohol; chloroform v ethyl alcohol; chloroform v isobutyl alcohol (Duncan's new multiple-range test).

Table 4

Weight loss of PMMA resin following 6 weeks immersion in test solvents

Solvent		Specimens 1	2	3	4	5	6	Mean	(S.D.)*
Benzene	Initial weight (mg)	5.50	7.75	6.80	8.50	7.15	6.20		
	Final weight (mg)	0.05	0.55	0.30	0.35	0.25	0.05		
	% Resin loss	99.1	92.9	95.6	95.9	96.5	99.2	96.5	(2.4)
Chloroform	Initial weight (mg)	8.85	7.00	6.05	5.35	6.95	6.50		
	Final weight (mg)	0.45	0.15	0.05	0.05	0.10	0.05		
	% Resin loss	94.9	97.9	99.2	99.1	98.6	99.2	98.2	(1.7)
Ethyl alcohol	Initial weight (mg)	7.95	4.40	4.75	6.15	6.15	4.50		
	Final weight (mg)	7.15	3.15	3.35	5.40	7.00	2.65		
	% Resin loss	10.1	28.4	29.5	12.2	0.0	41.1	20.2	(15.3)
Isobutyl alcohol	Initial weight (mg)	5.80	6.45	8.95	4.95	6.75	5.55		
	Final weight (mg)	4.95	4.80	8.15	4.05	5.00	4.45		
	% Resin loss	14.7	25.6	8.9	18.2	25.9	19.8	18.9	(6.5)

* Differences between the following mean values are significant at the 0.05 level: benzene v ethyl alcohol; benzene v isobutyl alcohol; chloroform v ethyl alcohol; chloroform v isobutyl alcohol (Duncan's new multiple-range test).

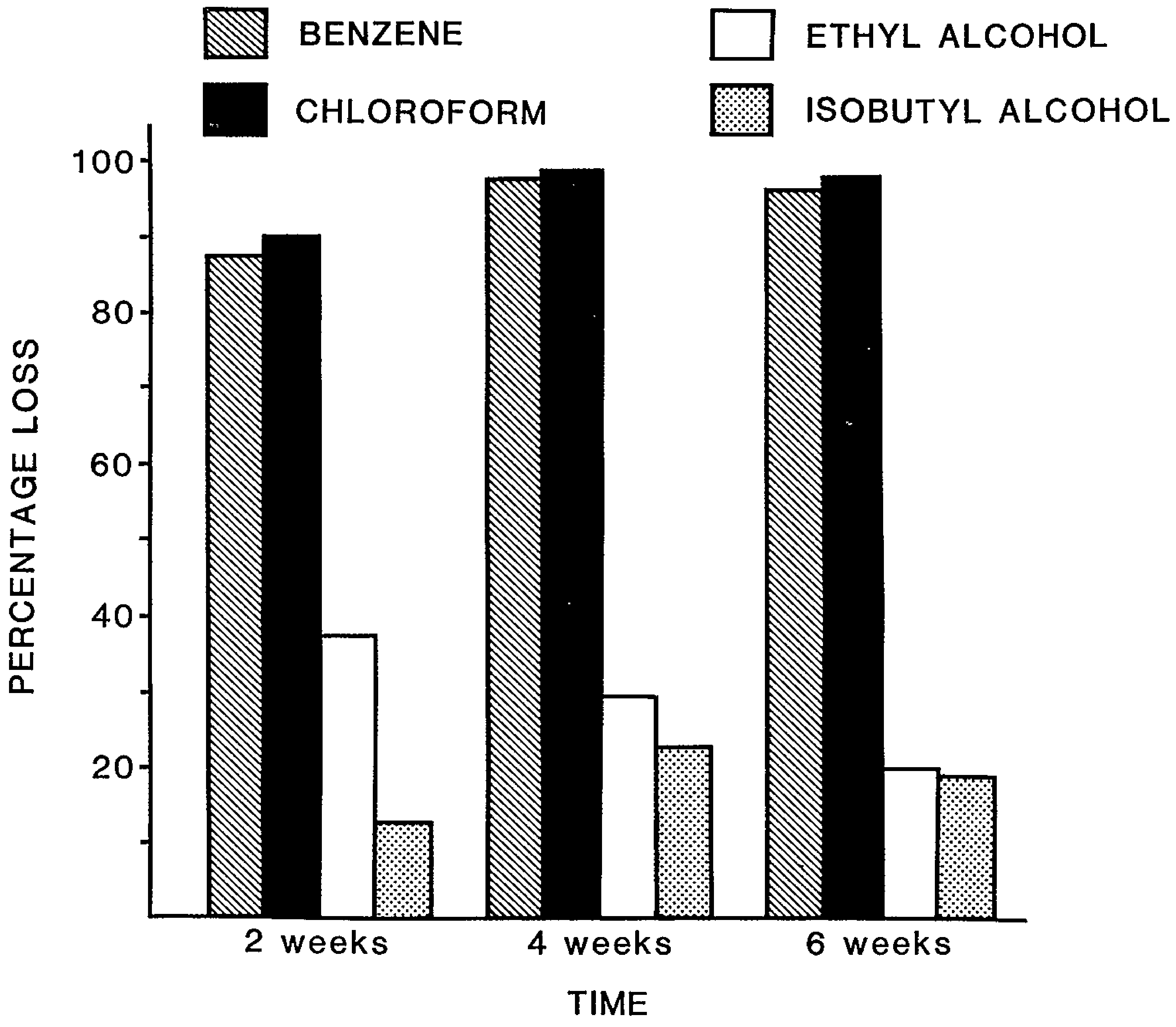

Figure 6

Mean percentage weight loss of PMMA resin in test solvents.

Figure 7 shows the appearance of the exposed surface of PMMA resin after placement and polymerisation and before immersion in a solvent. The surface is free of obvious defects.

Of the four solvents tested, benzene and chloroform produced the greatest weight loss of PMMA resin at each time interval. The mean weight loss of the resin in benzene was 87.5 per cent, 97.7 per cent and 96.5 per cent at 2 weeks, 4 weeks and 6 weeks respectively. The mean weight loss of the resin in chloroform was slightly higher being 90.0 per cent, 99.1 per cent and 98.2 per cent at 2 weeks, 4 weeks and 6 weeks respectively. However, the differences in the weight loss values between the resin in benzene and in chloroform were not statistically significant at any of the three time intervals (Tables 2 to 4).

The representative scanning electron micrographs of specimens after 6 weeks immersion in benzene (Figure 8) or chloroform (Figure 9) illustrate the efficacy of these solvents in removing PMMA resin. In both instances only a few scattered deposits can be seen remaining on the mesh surface.

As shown in Table 5, the resin-removing efficacy of benzene or chloroform, in terms of resin weight loss, increased significantly between 2 weeks and 4 weeks, and also between 2 weeks and 6 weeks. There was no significant increase in weight loss of PMMA resin between 4 weeks and 6 weeks, using either benzene or chloroform.

In contrast to benzene and chloroform, ethyl alcohol and isobutyl alcohol caused only minor weight loss of PMMA resin. The mean weight loss of the resin in ethyl alcohol was 37.6 per cent, 29.6 per cent and 20.2 per

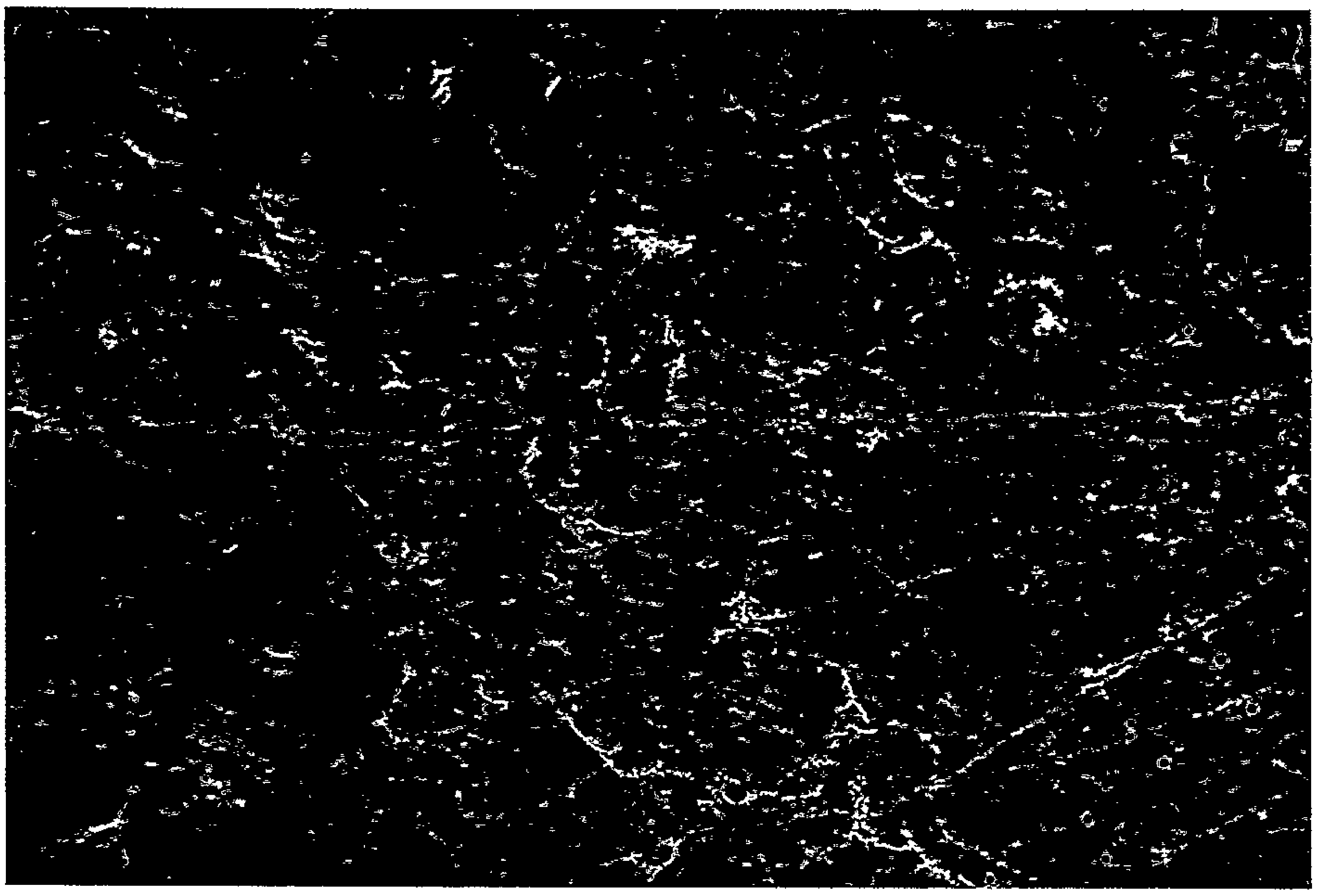

Figure 7

A scanning electron micrograph of the outer surface of PMMA resin after placement and polymerisation and prior to immersion in a solvent. There are no obvious surface defects. (Original magnification x60.)

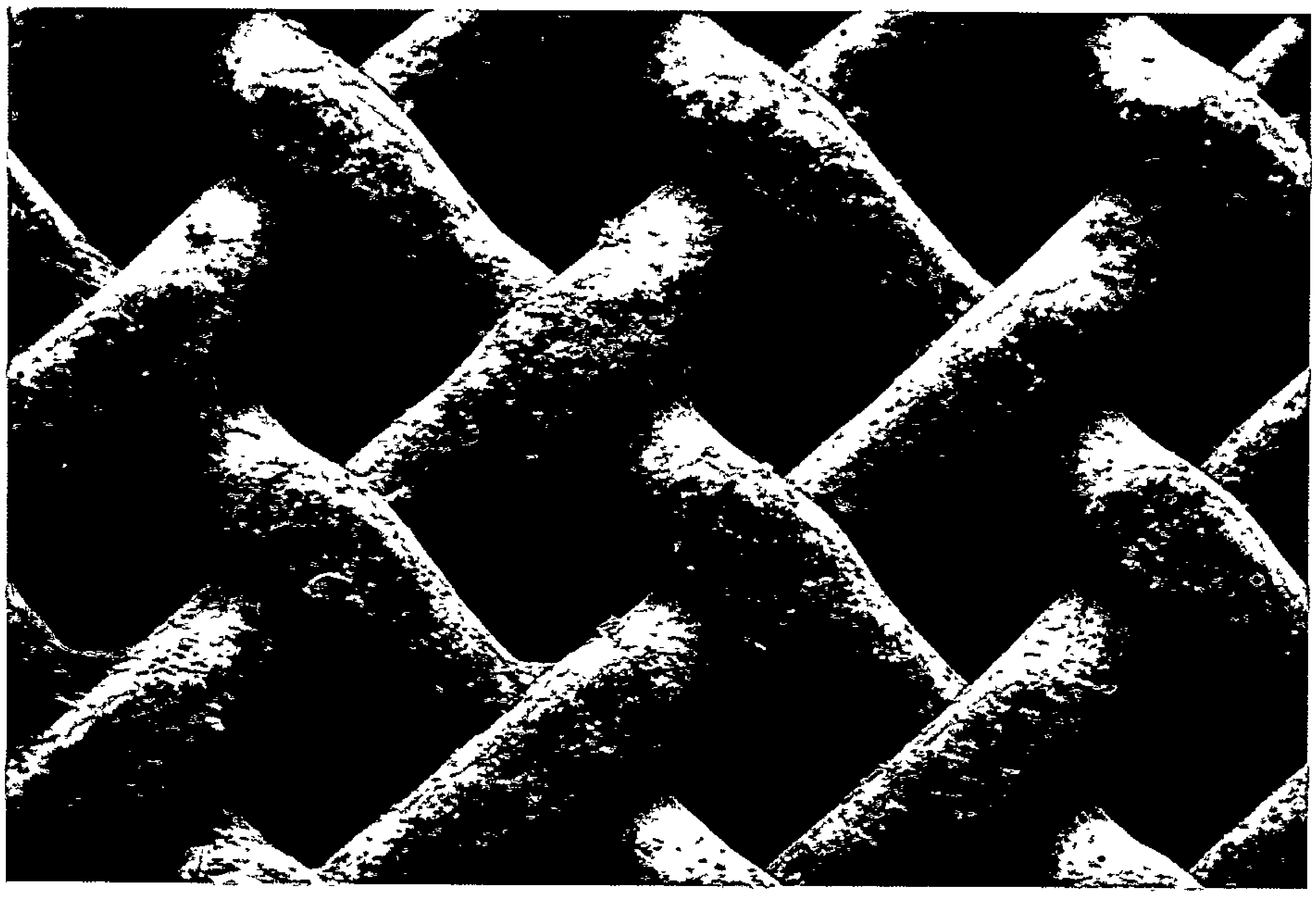

Figure 8

Appearance of a specimen from the PMMA resin group after 6 weeks immersion in benzene. Except for some deposits on the mesh surface, all the bonding resin appears to have been removed. (Original magnification x60.)

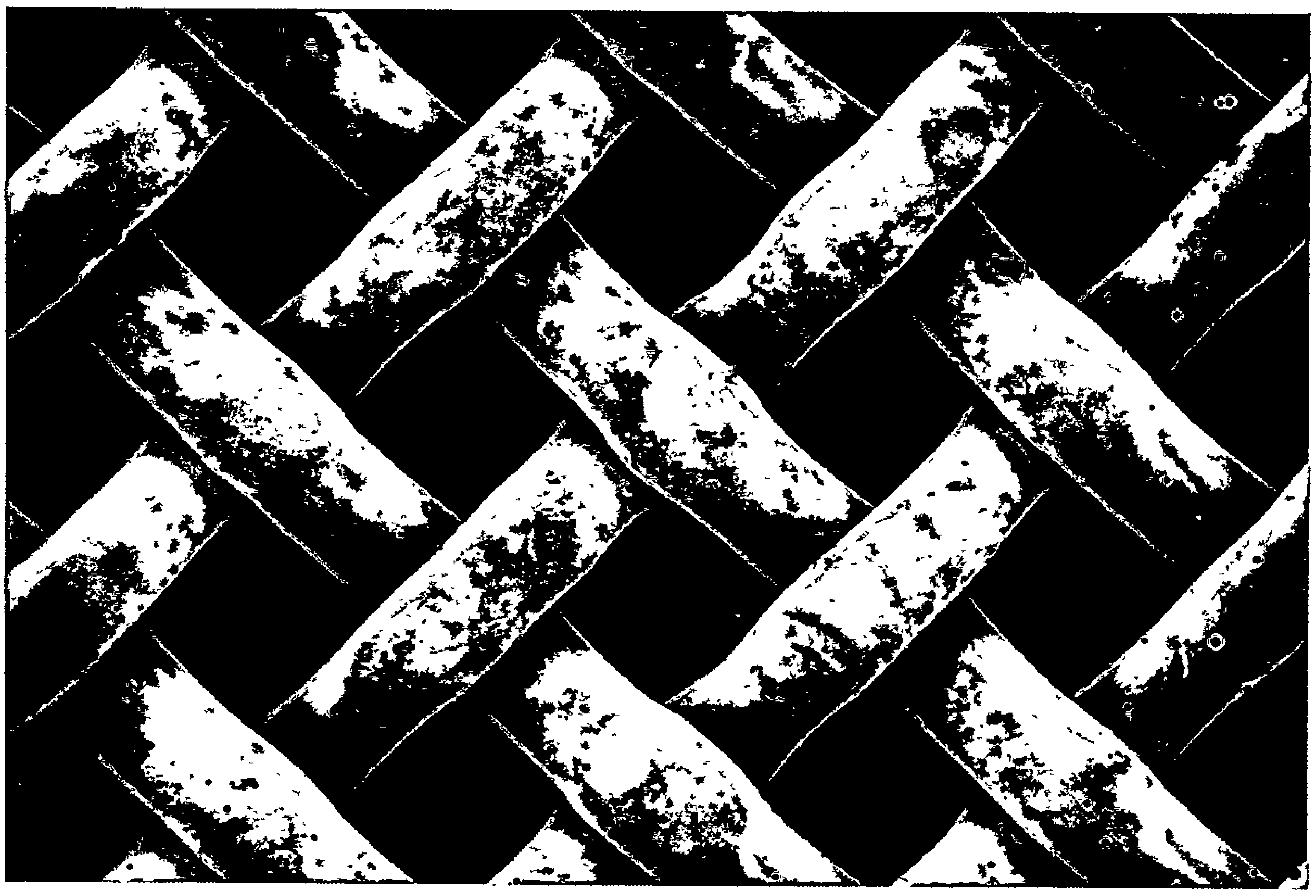

Figure 9

A scanning electron micrograph of a specimen from the PMMA group after 6 weeks immersion in chloroform. Apart from some minor deposits on parts of the mesh surface, there appears to have been a complete removal of resin. (Original magnification x60.)

Table 5

Effect of immersion period on weight loss of PMMA resin in test solvents*

Solvent	2 weeks v 4 weeks	2 weeks v 6 weeks	4 weeks v 6 weeks
Benzene	S**	S	NS†
Chloroform	S	S	NS
Ethyl alcohol	NS	S	NS
Isobutyl alcohol	NS	NS	NS

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* Based on data presented in Tables 2-4.

**S Significant at 0.05 level.
†NS Not significant at 0.05 level.
(Duncan's new multiple-range test)

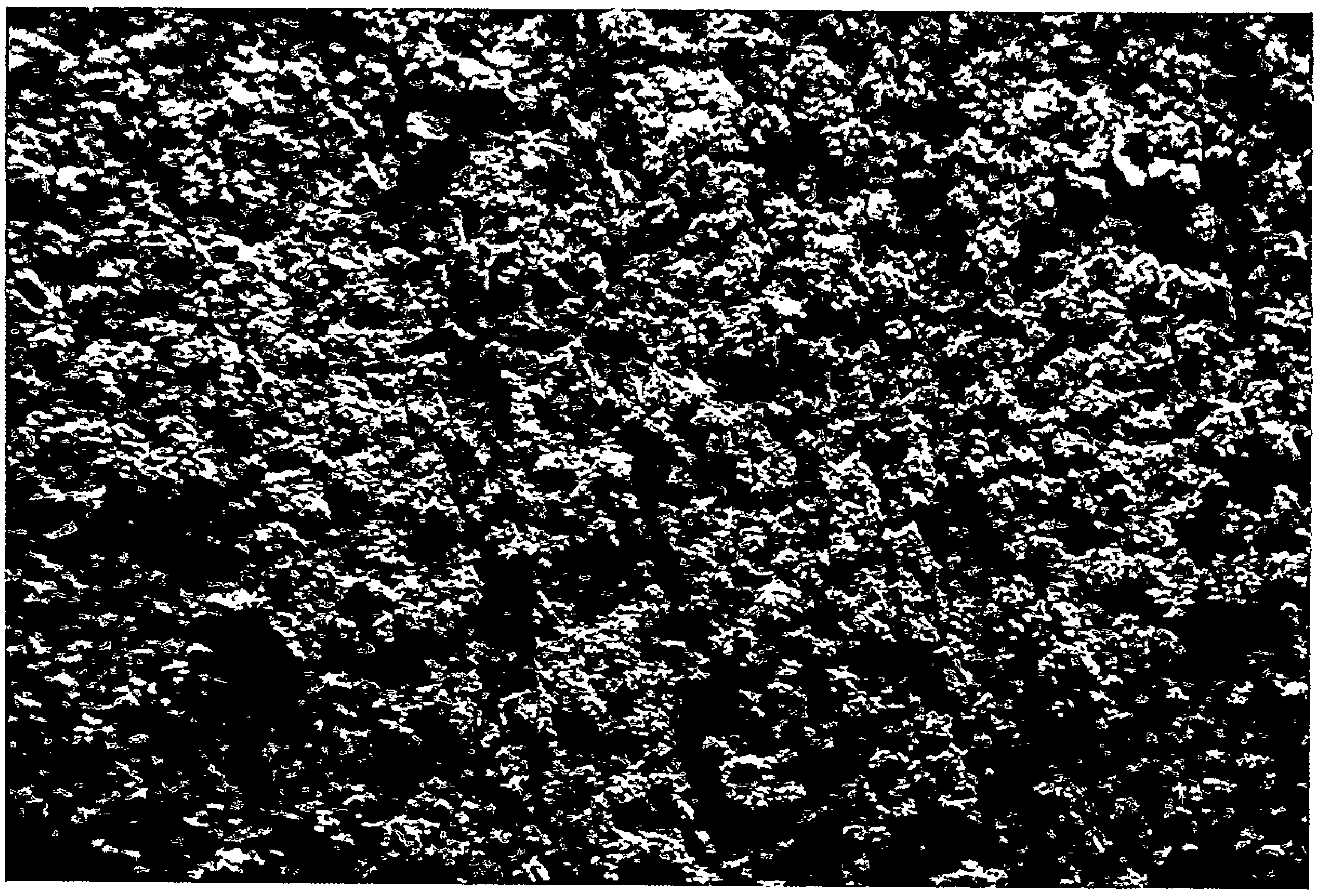

Figure 10

A 6-week immersion period in ethyl alcohol appears to have had only a limited effect on the surface of PMMA resin. There is no evidence of the underlying mesh framework having been exposed. (Original magnification x60.)

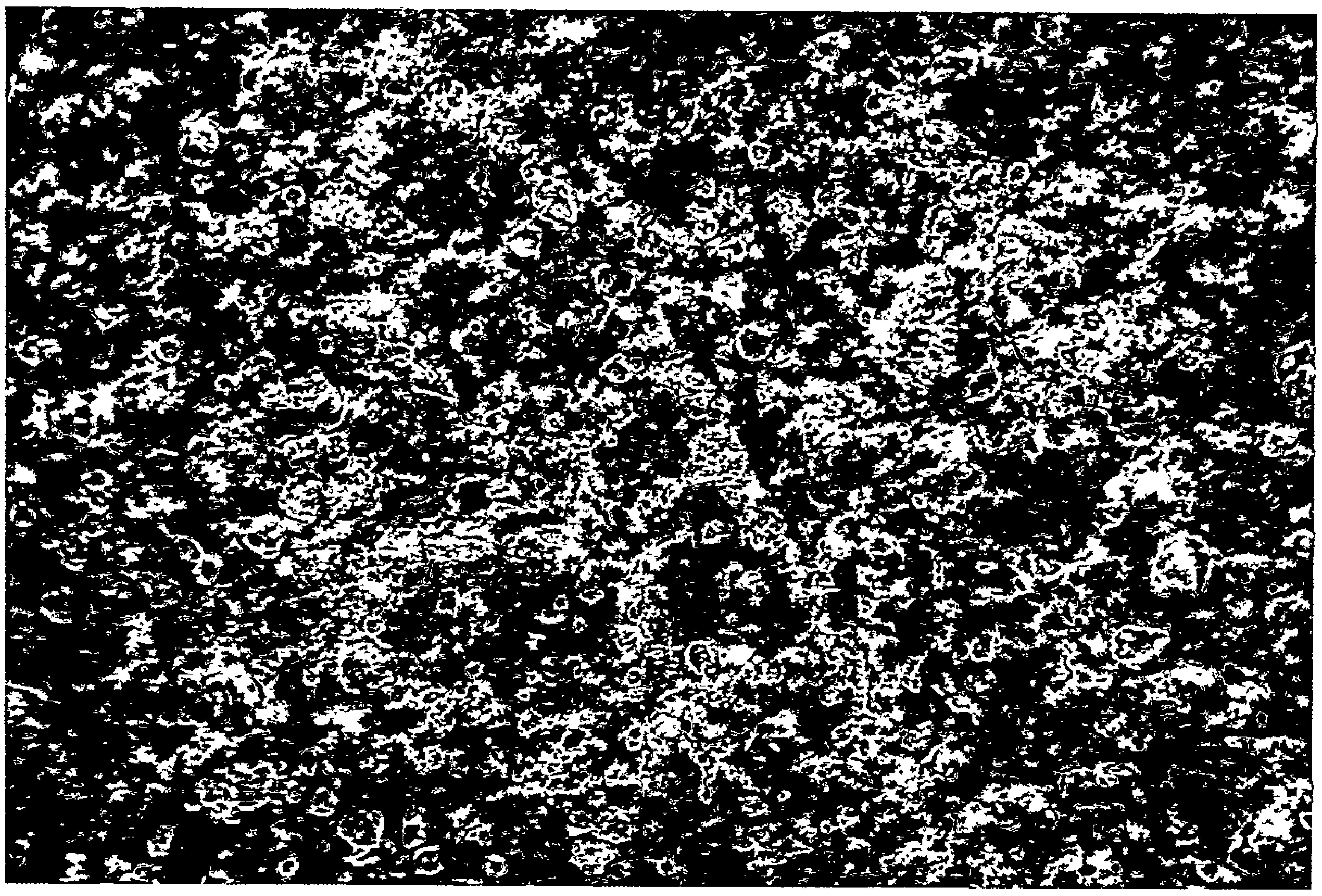

Figure 11

A scanning electron micrograph of the surface of PMMA resin after 6 weeks immersion in isobutyl alcohol. The solvent appears to have had little effect on the resin. Some minor defects are evident. (Original magnification x60.)

cent at 2 weeks, 4 weeks and 6 weeks respectively. The mean weight loss of the resin in isobutyl alcohol was 12.9 per cent, 22.8 per cent and 18.9 per cent at 2 weeks, 4 weeks and 6 weeks respectively (Tables 2 to 4).

Only at 2 weeks was the mean weight loss of PMMA resin in ethyl alcohol significantly higher than that in isobutyl alcohol ($p<0.05$). At each time interval the weight loss of PMMA resin in ethyl alcohol or isobutyl alcohol was significantly lower ($p<0.05$) than the corresponding values obtained with benzene or chloroform (Tables 2 to 4).

The resin-removal efficacy, in terms of weight loss, using ethyl alcohol deteriorated significantly ($p<0.05$) between 2 weeks and 6 weeks (Table 5). In contrast, the resin removal efficacy of isobutyl alcohol did not alter significantly during the course of the experiment (Table 5).

The representative scanning electron micrographs of the exposed surfaces of the PMMA resin after 6 weeks immersion in ethyl alcohol (Figure 10) or isobutyl alcohol (Figure 11) both show evidence of some solvent attack. In neither instance was the attack severe enough to expose the mesh surface of the underlying orthodontic bracket.

BIS-GMA Resin

Data on the weight loss of BIS-GMA resin in the test solvents at each time interval are presented in Tables 6 to 8. The findings in terms of percentage weight loss are summarised in the histogram presented in Figure 12.

Table 6

Weight loss of BIS-GMA resin following 2 weeks immersion in test solvents

Solvent		Specimens							
		1	2	3	4	5	6	Mean	(S.D.)*
Benzene	Initial weight (mg)	6.30	6.95	7.55	6.10	7.00	7.35		
	Final weight (mg)	5.50	6.30	6.80	5.40	6.25	6.95		
	% Resin loss	12.7	9.4	9.9	11.5	10.7	5.4	9.9	(2.5)
Chloroform	Initial weight (mg)	7.95	7.35	7.75	7.25	7.95	8.35		
	Final weight (mg)	1.00	0.70	1.80	1.20	0.75	0.70		
	% Resin loss	87.4	90.5	76.8	83.5	90.6	91.6	86.7	(5.7)
Ethyl alcohol	Initial weight (mg)	6.90	7.95	7.35	7.40	5.20	7.20		
	Final weight (mg)	6.05	6.70	6.90	7.10	4.35	7.95		
	% Resin loss	12.3	15.7	6.1	4.1	16.4	0.0	9.1	(6.7)
Isobutyl alcohol	Initial weight (mg)	7.75	7.35	8.10	9.55	8.20	7.45		
	Final weight (mg)	7.35	6.90	7.40	8.75	7.55	7.20		
	% Resin loss	5.2	6.1	8.6	8.4	7.9	3.4	6.6	(2.1)

* Differences between the following mean values are significant at the 0.05 level: benzene v chloroform; chloroform v ethyl alcohol; chloroform v isobutyl alcohol (Duncan's new multiple-range test).

Table 7

Weight loss of BIS-GMA resin following 4 weeks immersion in test solvents

Solvent		Specimens							
		1	2	3	4	5	6	Mean	(S.D.)*
Benzene	Initial weight (mg)	8.65	7.45	8.25	8.45	8.65	6.70		
	Final weight (mg)	7.10	6.75	7.20	7.30	7.40	0.85		
	% Resin loss	17.9	9.4	12.7	13.6	14.5	87.3	25.9	(30.2)
Chloroform	Initial weight (mg)	8.70	8.35	9.45	7.10	11.40	3.55		
	Final weight (mg)	0.55	0.30	0.45	0.60	0.70	0.65		
	% Resin loss	93.7	96.4	95.2	91.6	93.9	81.7	92.1	(5.3)
Ethyl alcohol	Initial weight (mg)	9.65	8.45	8.95	8.15	7.70	7.90		
	Final weight (mg)	7.55	7.25	7.40	7.20	7.00	7.20		
	% Resin loss	21.8	14.2	17.3	11.7	9.1	8.9	13.8	(5.0)
Isobutyl alcohol	Initial weight (mg)	7.65	7.70	8.45	7.75	7.90	9.00		
	Final weight (mg)	7.30	7.20	7.60	7.00	7.15	7.55		
	% Resin loss	4.6	6.5	10.1	9.7	9.5	16.1	9.4	(3.9)

* Differences between the following mean values are significant at the 0.05 level: benzene v chloroform; chloroform v ethyl alcohol; chloroform v isobutyl alcohol (Duncan's new multiple-range test).

Table 8

Weight loss of BIS-GMA resin following 6 weeks immersion in test solvents

Solvent		Specimens							
		1	2	3	4	5	6	Mean	(S.D.)*
Benzene	Initial weight (mg)	8.35	8.60	9.10	9.45	7.95	7.95		
	Final weight (mg)	5.40	6.15	2.35	1.80	1.25	2.80		
	% Resin loss	35.3	28.5	74.2	81.0	84.3	64.8	61.4	(23.9)
Chloroform	Initial weight (mg)	7.70	7.85	8.75	9.35	7.30	7.80		
	Final weight (mg)	0.55	0.50	1.40	0.55	0.60	0.55		
	% Resin loss	92.9	93.6	84.0	94.1	91.8	93.0	91.6	(3.8)
Ethyl alcohol	Initial weight (mg)	9.00	6.85	6.60	6.25	7.40	7.35		
	Final weight (mg)	6.90	6.10	5.95	5.60	6.70	6.50		
	% Resin loss	23.3	11.0	9.9	10.4	9.5	11.6	12.6	(5.3)
Isobutyl alcohol	Initial weight (mg)	8.00	8.35	7.60	7.90	8.30	8.05		
	Final weight (mg)	7.55	7.80	7.10	6.95	7.65	7.40		
	% Resin loss	5.6	6.6	6.6	12.0	7.8	8.1	7.8	(2.3)

* Differences between the following mean values are significant at the 0.05 level: benzene v chloroform; benzene v ethyl alcohol; benzene v isobutyl alcohol; chloroform v ethyl alcohol; chloroform v isobutyl alcohol (Duncan's new multiple-range test).

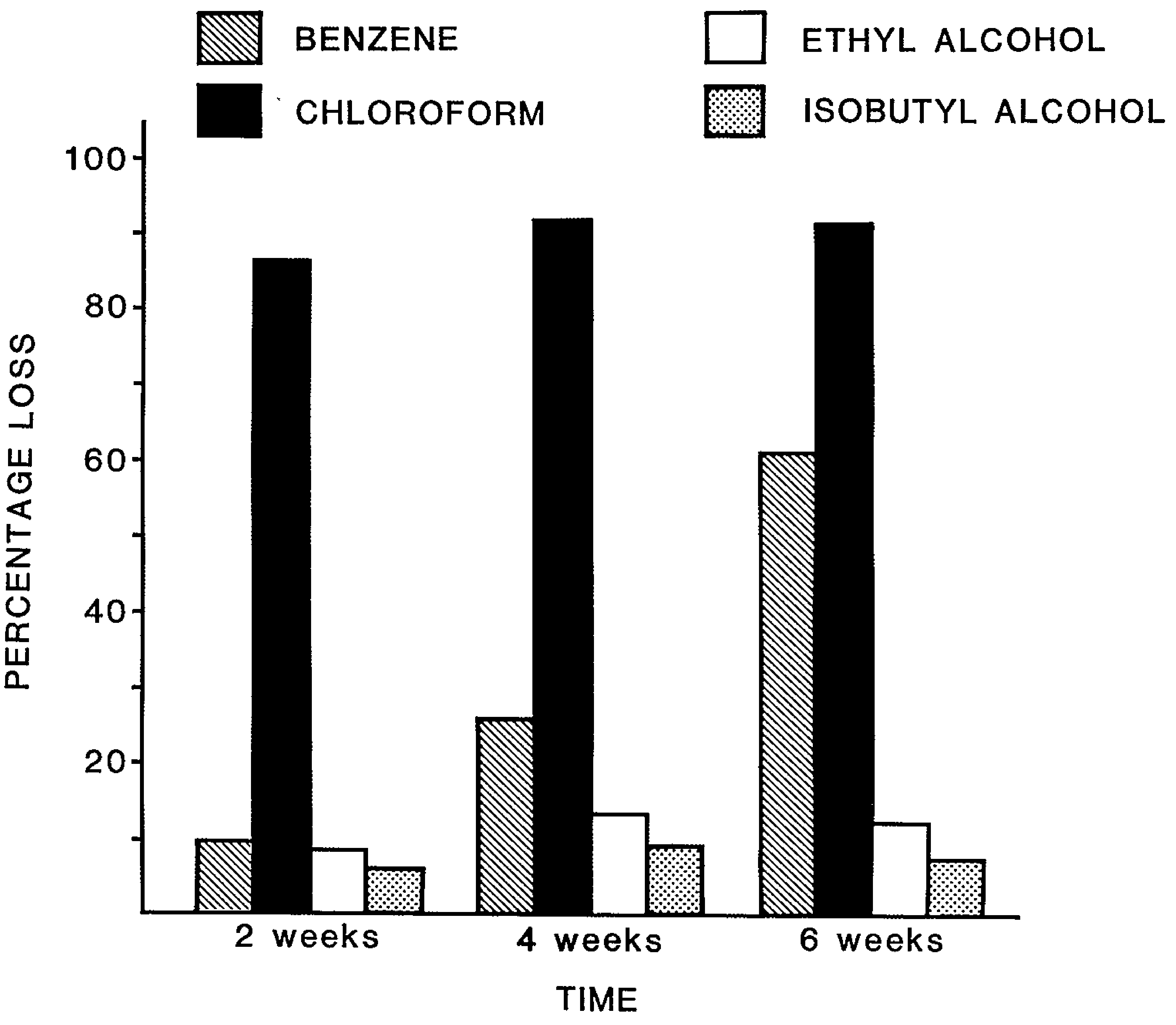

Figure 12

Mean percentage weight loss of BIS-GMA resin in test solvents.

The appearance of the exposed surface of BIS-GMA resin, after placement and polymerisation and prior to immersion in a solvent is shown in the scanning electron micrograph in Figure 13. There are no obvious defects.

Only one of the four solvents tested, chloroform, consistently caused a pronounced weight loss of BIS-GMA resin. The mean weight loss of BIS-GMA resin in chloroform was 86.7 per cent, 92.1 per cent and 91.6 per cent at 2 weeks, 4 weeks and 6 weeks respectively. At each time interval, the weight loss of BIS-GMA resin in chloroform was significantly higher ($p<0.05$) than the corresponding weight loss values of the resin in benzene, ethyl alcohol or isobutyl alcohol (Tables 6 to 8).

In terms of weight loss, the resin-removing efficacy of chloroform did not increase significantly with immersion time (Table 9).

A scanning electron micrograph of a BIS-GMA resin surface after 6 weeks immersion in chloroform is shown in Figure 14. The mesh surface is exposed, although some remnants of the resin are still evident.

The mean weight loss of BIS-GMA resin in benzene increased significantly from 9.9 per cent at 2 weeks to 61.4 per cent at 6 weeks ($p<0.05$). By 6 weeks the weight loss of the resin in benzene had reached a level which was significantly higher ($p<0.05$) than the corresponding weight loss in either ethyl alcohol or isobutyl alcohol. However, at none of the three time intervals did benzene equal the resin-removing efficacy of chloroform (Tables 6 to 8).

As shown in Table 9, the resin-removing efficacy of benzene, in terms of weight loss, increased significantly after 4 weeks ($p<0.05$).

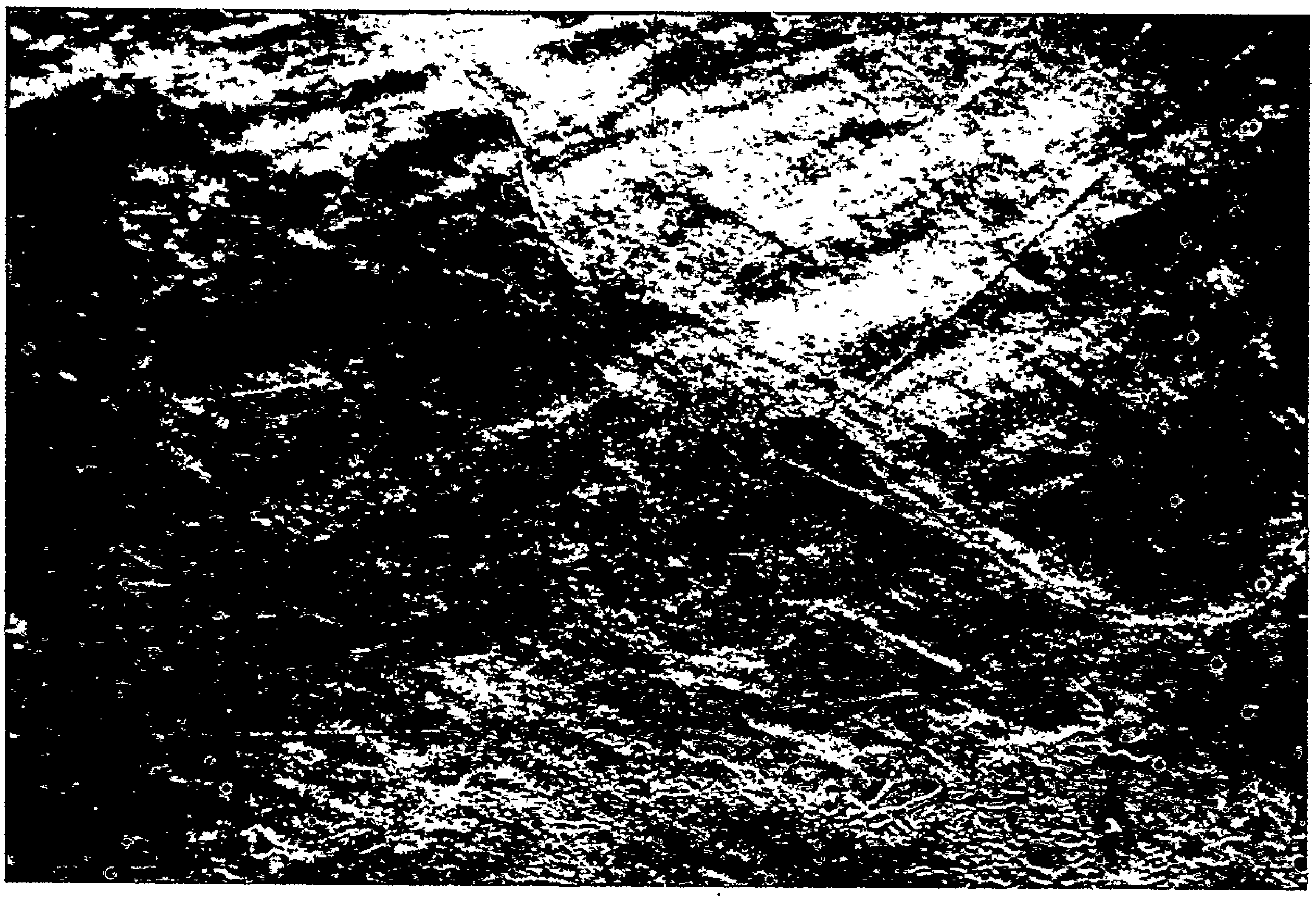

Figure 13

A scanning electron micrograph of the outer surface of BIS-GMA resin after placement and polymerisation and prior to immersion in a solvent. The surface is free of obvious defects. (Original magnification x60.)

Table 9

Effect of immersion period on weight loss of BIS-GMA resin in test solvents*

Solvent	2 weeks v 4 weeks	2 weeks v 6 weeks	4 weeks v 6 weeks
Benzene	NS†	S**	S
Chloroform	NS	NS	NS
Ethyl alcohol	NS	NS	NS
Isobutyl alcohol	NS	NS	NS

* Based on data presented in Tables 6-8.

**S Significant at 0.05 level.
†NS Not significant at 0.05 level.
(Duncan's new multiple-range test)

Figure 14

Appearance of a specimen from the BIS-GMA group after 6 weeks immersion in chloroform. Although the surface of the meshwork has been exposed, some resin remnants are quite evident. (Original magnification x60.)

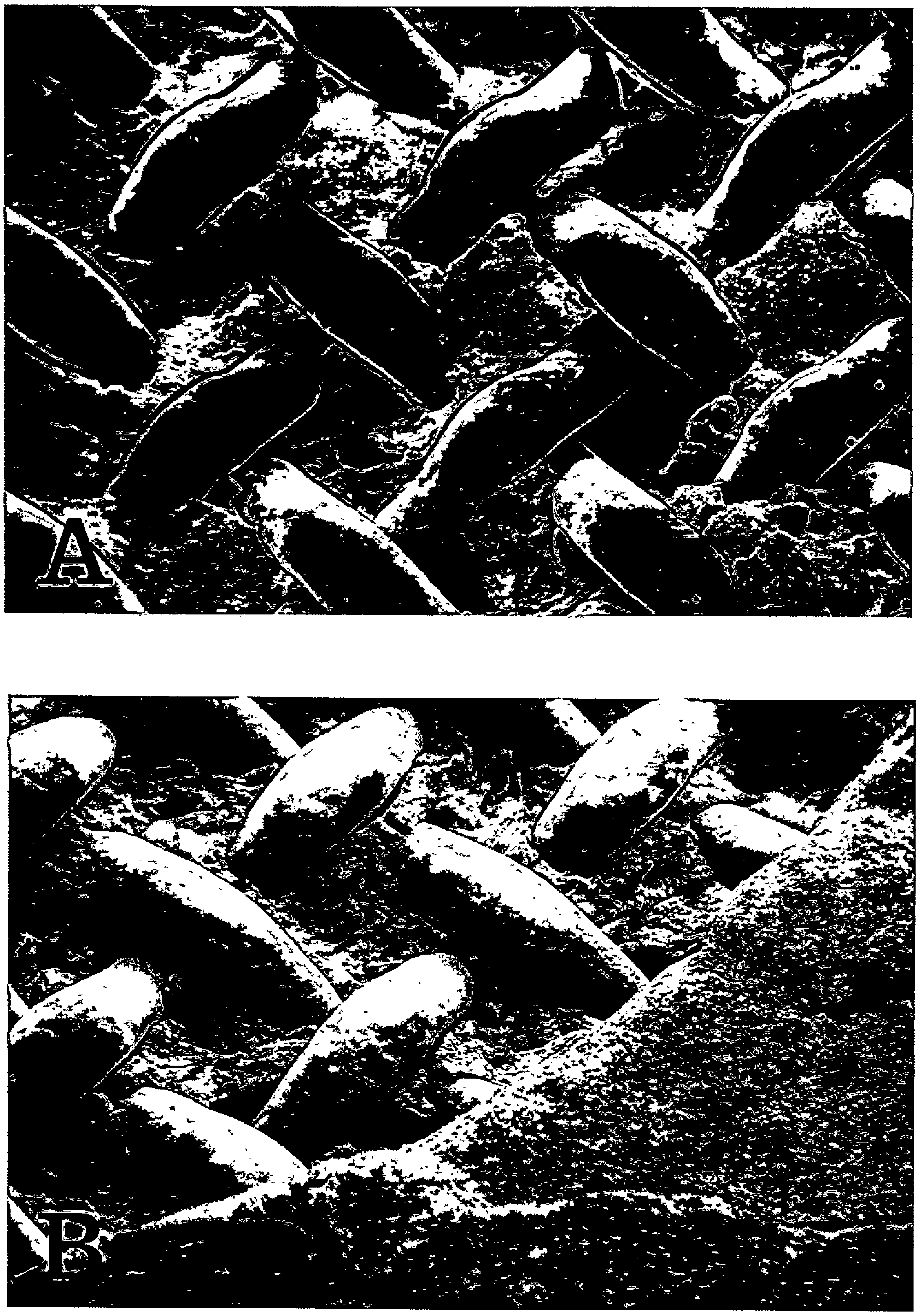

Figure 15

Scanning electron micrographs showing the two types of resin-removal pattern observed with specimens from the BIS-GMA group after 6 weeks immersion in benzene. A, The mesh surface has been exposed but resin is still present between the meshwork. B, Part of the resin overlying the meshwork has been removed. The remainder of the meshwork remains covered by resin. (Original magnification x60.)

Figure 16

Appearance of the surface of BIS-GMA resin after 6 weeks exposure to ethyl alcohol. The solvent appears to have had little effect on the surface. (Original magnification x60.)

Figure 17

A scanning electron micrograph of the surface of BIS-GMA resin after 6 weeks immersion in isobutyl alcohol. The surface appears to have been only slightly roughened. (Original magnification x 60.)

Illustrated in Figures 15A and 15B are scanning electron micrographs showing the two types of resin-removal pattern observed following 6 weeks immersion in benzene. In all specimens the resin remained between the meshwork. In some instances the entire layer of resin overlying the meshwork was removed (Figure 15A), whereas in others there was only partial removal of this layer (Figure 15B).

Neither ethyl alcohol or isobutyl alcohol had a pronounced effect on the weight loss of BIS-GMA resin at any of the three time intervals (Tables 6 to 8). The lowest mean weight loss value for the resin in these two solvents was 6.6 per cent for isobutyl alcohol at 2 weeks, whereas the highest weight loss value was 13.8 per cent for ethyl alcohol at 4 weeks. There was no statistically significant difference in the weight loss values for BIS-GMA resin in either ethyl alcohol or isobutyl alcohol at 2 weeks, 4 weeks or 6 weeks (Table 9).

The representative scanning electron micrographs in Figures 16 and 17 show that a 6-week immersion period in ethyl alcohol or isobutyl alcohol had little discernible effect on the surface of BIS-GMA resin.

DISCUSSION

All four solvents used in this study had solubility parameters within the range associated with the softening of PMMA resin and BIS-GMA resin (Burrell, 1975; Wu and McKinney, 1982). Despite this, two of the solvents, ethyl alcohol and isobutyl alcohol, were relatively ineffective in reducing the weight of the PMMA and BIS-GMA bonding resins tested. Neither solvent removed sufficient resin to expose the mesh base of the metallic direct-bond orthodontic brackets used in this investigation.

In contrast, chloroform removed virtually all the PMMA resin from the mesh base of the brackets. Furthermore, it was significantly more effective than benzene in reducing the weight of the BIS-GMA bonding resin during the 2-week, 4-week and 6-week solvent immersion periods. Although 6 weeks immersion in chloroform removed sufficient BIS-GMA resin to expose the mesh base, remnants of the resin were still present.

Benzene was not significantly different to chloroform in its effect on PMMA resin, but it was far less effective than chloroform in degrading the BIS-GMA bonding resin. It was apparent from visual inspection of the specimens and from scanning electron micrographs that a prime site for the attack of benzene on BIS-GMA resin was the interface between the resin and the outer mesh surface.

The effectiveness of benzene and chloroform in removing PMMA resin was not unexpected in view of the limited amount of cross-linking likely to have been present in the set material (Phillips, 1982). However, the level of resin loss encountered when the BIS-GMA bonding resin was immersed in chloroform was higher than anticipated because of the extensive cross-linking normally found in this material (Greener *et al.*, 1972). One possible explanation is that, the BIS-GMA bonding resin may not have been fully cured or polymerised. Thompson *et al.*, (1982) have shown that significant amounts of unpolymerised material remain in cured orthodontic bonding resins. In addition, Asmussen (1982a; 1982b) has shown that cured BIS-GMA resin can contain many unreacted double bonds, and these could have been sites for solvent action and subsequent polymer degradation (Asmussen, 1984).

Whether the amount of BIS-GMA resin removed by chloroform was sufficient to enable adequate rebonding of the brackets is not known. Reduced tensile bond strength (Wright and Powers, 1985) and shear bond strength (Mascia and Chen, 1982) have been reported when metallic direct-bond brackets were recycled, using a commercial chemically-based reconditioning process. However, in contrast, Buchman (1980) reported no loss in tensile bond strength in brackets recycled using the same commercial chemical reconditioning process. No comparisons with the commercial reconditioning process and the procedures followed in this study can be made, because the company involved has not divulged details of the process employed, including the type of chemical or chemicals used.

Various techniques have been described in the literature that could be employed to test the bond strength of brackets subjected to the solvent treatment used in this study. The brackets could be bonded to either the exposed enamel surfaces of teeth embedded in acrylic (Mascia and Chen, 1982; Wheeler and Ackerman, 1983), or bonded directly to plastic rods

(Wright and Powers, 1985) and then subjected to either shear or tensile forces. Another method, that used by McClea and Wallbridge (1986), may also provide useful information. In their method, two recycled brackets are bonded together, mesh base to mesh base using an appropriate resin, and then subjected to tensile forces.

Despite the apparently limited use of PMMA resin as a direct bonding agent (Gorelick, 1979), the results of this study suggest that the recycling of brackets bonded with PMMA resin would be a fairly straightforward process, if chloroform is used as the solvent. The few remaining deposits seen in the representative scanning electron micrograph of the mesh base of a bracket treated with this solvent (Figure 9), would be unlikely to constitute a major impediment to newly placed bonding resin flowing in and around the mesh base. Apart from simplicity, the advantage of such an approach is that no heating of the bracket is required, and therefore the likelihood of untoward effects, such as corrosion (Buchman, 1980) should be minimal.

A potential advantage of chemical reconditioning processes, over those that require raised temperatures, is that the application of heat to stainless steel brackets above 752° to 842°F (400° to 450°C) can cause carbide precipitation and subsequent corrosion (Sutow and Pollack, 1981; Phillips, 1982). Furthermore, the oxide surface film on stainless steel, which imparts resistance to tarnish and corrosion (Sutow and Pollack, 1981; Williams, 1981), is unlikely to be disrupted by chemically-based procedures.

The findings of the present study suggest the possibility of developing chemically-based processes for the removal of bonding resins from metallic direct-bond orthodontic brackets, that can be used in the orthodontic surgery. However, much more developmental work is required to establish the feasibility of this approach.

It must be emphasised that the experiments in this study were carried out at 37°C. The possibility therefore exists that an increased level of BIS-GMA resin removal could have been achieved, especially using chloroform as the solvent, if the temperature had been raised for example to 60°C (ASTM D 543 - 67; ASTM D 1239 - 55). Solubility normally increases with rising temperature (Fuchs and Suhr, 1975).

A further possibility for enhanced removal of BIS-GMA resin is the use of a combination of solvents. Fuchs and Suhr (1975) have suggested that in some circumstances this approach can be used to facilitate resin removal. However, no reports were found to substantiate this claim in terms of BIS-GMA resins. The possibility also exists that the use of agitation in combination with the appropriate solvent or solvents may accelerate resin breakdown (Billmeyer, 1971).

Following the removal of metallic direct-bond orthodontic brackets, invariably resin tags are left embedded in the enamel surface (Caspersen, 1977). At present these are removed by mechanical instruments such as stones, wheels, sandpaper disks and tungsten carbide or diamond burs (Retief and Denys, 1979; Zachrisson and Arthun, 1979). Scaling by hand, ultrasonics and the use of band removing pliers have also been suggested (Reynolds, 1975). Finally the teeth are polished using a rubber cup or bristle brush and prophylactic paste. Possible disadvantages of these procedures include deep scratches on the tooth surface (Zachrisson and Arthun, 1979; Rouleau *et al.*, 1982) and a significant loss of enamel (Fitzpatrick and Way, 1977; Thompson and Way, 1981). Removal of brackets may produce enamel tearouts to a depth of 100 µm and together with subsequent clean-up procedures, a loss of up to 10 per cent of the original enamel surface is possible (Diedrich, 1981). The difficulties encountered in debonding has led to the suggestion by Reynolds (1975) and Maijer (1982) that solvents could play a role in this process.

Although the solvent application times used in this study are much longer than could be employed in the mouth, it is possible that some resin removal from enamel could be achieved by topical application of the appropriate solvent or solvent combination. If removal occurred, the amount removed would undoubtedly be greater if PMMA rather than BIS-GMA was used as the bonding resin.

Reduced bond strengths have been reported with the use of PMMA resins, as compared to BIS-GMA, orthodontic bonding resins (Faust *et al.*, 1978). However, the increased bond strength of BIS-GMA resins may not be necessary for successful bonding of orthodontic brackets. Reynolds (1975) has suggested that an ideal tensile bond strength for orthodontic bonding resins is approximately 60 to 80 kg/cm^2. A study of tensile bond strengths of PMMA and BIS-GMA resins for orthodontic bonding (Buzzitta *et al.*, 1982) indicate that both would fulfil this requirement. However, bond strengths exceeding this range, have recently been reported with the PMMA resin used in the present investigation (Miura, 1986).

The main disadvantages of BIS-GMA bonding resins, especially those that are heavily filled, concern difficulties with debonding, in particular the possibility of damage to the enamel surface during resin removal. (Gwinnett and Gorelick, 1977). Removal of attachments bonded with lightly filled or unfilled resins, should result in failure within the resin rather than at the resin-enamel interface, and thereby minimise the possibility of fractures occurring in the etched enamel surface (Retief, 1974). In the case of PMMA orthodontic bonding resins, Brown and Way (1978) have shown that these materials cause less surface enamel loss than their filled BIS-GMA counterparts, during debonding procedures.

SUMMARY AND CONCLUSIONS

This study was carried out to determine the effect of four common organic solvents, benzene, chloroform, ethyl alcohol and isobutyl alcohol, on the weight loss of PMMA and BIS-GMA orthodontic bonding resins attached to the mesh base of metallic direct-bond orthodontic brackets. Two commercially available orthodontic resins, *Orthomite Super-Bond* (a PMMA resin) and *Monolok* (a BIS-GMA resin) were used.

The mesh surface of each bracket was covered with either PMMA resin or BIS-GMA resin, which had been prepared and applied according to the manufacturer's directions. Each bracket was placed resin surface downwards on a PTFE surface under a constant force of 8 oz (227 g) via a Dontrix Pressure Gauge, for a period of 5 minutes, and allowed to polymerise undisturbed for 7 days at room temperature. Specimens were then removed and weighed, before being immersed in 20 ml of solvent in a sealable 50 ml glass container and placed in an incubator at 37°C. The solvent was renewed every 7 days, for either 2 weeks, 4 weeks or 6 weeks. At the end of the appropriate immersion period, specimens were placed in new solvent in a glass container in an ultrasonic cleaner, which was then activated for 10 minutes. The final weight of each specimen was determined 7 days later, after it had been allowed to air dry, under cover, at room temperature.

Both the PMMA resin and BIS-GMA resin were affected to varying degrees by the solvents used. Chloroform and benzene were highly effective in removing PMMA resin. At 6 weeks alone, the mean weight loss value with chloroform was 98.2 per cent and with benzene was 96.5 per cent. Markedly lower weight loss values of PMMA resin were achieved when the material was exposed to either ethyl alcohol or isobutyl alcohol. The highest mean weight loss value with ethyl alcohol was 37.6 per cent at 2 weeks, and with isobutyl alcohol it was 22.8 per cent at 4 weeks.

Chloroform produced the highest mean weight loss values (86.7 to 92.1 per cent) in the BIS-GMA resin samples tested. The resin removing efficacy of benzene was greatest at 6 weeks (mean weight loss value of 61.4 per cent), although at no time interval was it as efficient as chloroform. Neither ethyl alcohol or isobutyl alcohol had a pronounced effect on the weight loss of BIS-GMA resin at any of the three time intervals. The highest mean weight loss value recorded for ethyl alcohol was 13.8 per cent at 4 weeks, and for isobutyl alcohol, 9.4 per cent, also at 4 weeks.

Of the four solvents tested, chloroform showed the highest resin removing efficiency overall. Benzene was quite effective in degrading PMMA resin, but only moderately effective in removing BIS-GMA resin. On the basis of the findings in this study, ethyl alcohol and isobutyl alcohol appear to have little potential in the chemical removal of PMMA or BIS-GMA bonding resins from orthodontic brackets.

APPENDIX I

Weights of unbonded brackets after a 6-week immersion period in test solvents

Solvent		Specimens					
		1	2	3	4	5	6
Benzene	Initial weight (mg)	86.40	86.10	85.85	86.25	84.20	87.05
	Final weight (mg)	86.35	86.05	86.00	86.15	84.20	87.05
Chloroform	Initial weight (mg)	84.85	85.50	86.20	85.50	85.05	85.25
	Final weight (mg)	84.90	85.50	86.20	85.45	85.15	85.20
Ethyl alcohol	Initial weight (mg)	85.35	86.00	85.50	85.70	85.10	85.85
	Final weight (mg)	85.35	85.95	85.40	85.70	85.20	85.90
Isobutyl alcohol	Initial weight (mg)	85.45	85.75	87.40	84.65	85.15	86.50
	Final weight (mg)	85.45	85.65	87.40	84.75	85.20	86.45

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