

Water sorption, solubility and monomer elution from three commercial orthodontic adhesives

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Objectives: The aims of this study were to study the water sorption, water solubility, and elution of three monomers Bis-GMA, TEGDMA, and BPA of three commercial orthodontic adhesives up to 7 d.

Materials and methods: The water sorption, water solubility and monomer elution from three commercial adhesives; one chemically cured; Unite (Unitek Corp., Monrovia, CA, USA), two light-cured; Enlight (Ormco, Glendora, California, USA), and Grengloo (Ormco, Glendora, California, USA) were determined at four interval times of 1,3,5, and 7 d immersion. The adhesive specimen was prepared by polymerization in a cylindrical stainless steel mold with a diameter of 10 mm and 1 mm thickness. The water sorption and solubility protocol were done according to ISO 4049 specification. The concentration of Bis-GMA, TEGDMA, and BPA from the immersion medium was determined using High-performance liquid chromatography (HPLC). One-way ANOVA followed by Dunnett T3 test for water sorption and Tukey's for elution test were done for multiple comparisons.

Results: Water sorption and water solubility were found to increase with storage time. It was found that they had similar water sorption and water solubility at 1 d ($p>0.05$) but differences were found at other time intervals ($p<0.05$). All adhesives had significant differences in water sorption and solubility between 1 d and 7 d ($p<0.05$). Enlight and Unite had Bis-GMA, TEGDMA, and BPA elution at all time intervals, however in varied amount. Grengloo contains no Bis-GMA in the immersion medium at all time intervals. They were significant differences among elution of the different adhesives at the same time ($p<0.05$) and among time intervals of the same adhesive ($p<0.05$) except Bis-GMA elution of Enlight at 1 d and 7 d ($p>0.05$) and BPA elution of Unite at 1 d and 7 d ($p<0.05$) which had similar results. Pearson's correlation coefficient were found high correlation between water sorption and solubility ($R^2 = 0.988$). Only TEGDMA at 3 and 5 d found correlation with water sorption ($R^2=0.754$), and sol ($R^2=0.878$)

Conclusion: Water sorption and solubility of light-cure and chemically cured adhesives increase with storage time. The amount of monomer leached from the polymerized specimen from all adhesives seems to be varied.

Keywords: Elution, Orthodontic adhesive, water solubility, water sorption

How to cite:

Introduction

For the most patient's comfort and effective in orthodontics, brackets are designed to hold the orthodontic devices. Bonding the brackets to tooth structure needs orthodontic adhesives. High quality orthodontic adhesive resins offer good physical properties and benefits. The orthodontic adhesives available in the market can be classified

by polymerization into self-cure, light-cure, and dual-cure. Self-cure allows some time for practitioner before the resin become harden with chemical reaction after mixing two components together. For light-cure, there is only single component, only irradiation from curing unit can initiate the polymerization in the adhesive materials within seconds so practitioner can manage their operating time. Recently, color-change orthodontic adhesive is introduced

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Received :

Accepted :

to allow practitioners to easily see the boundary and easily remove the excessive amount of adhesive before polymerization by light-curing.

In order to understand the characteristics and limitations of the different orthodontic adhesives with different compositions, many physical properties have been studied. Polymerization is one of the most important factor that affect the resin properties¹⁻². After initiation of polymerization, either self-cure or light-cure, the monomer connects into long chains by radical polymerization. Once, the radicals at the ends of two chains or two monomers connected, the chain reaction polymerization is terminated³. Normally, the monomers in the components are not totally consumed. Some of the monomer remains and trapped within the resin materials ready to be released⁴. Moreover, adhesive utilization within oral environment can lead the resin to moist absorption². Water sorption influences the resins strength, biocompatibility, dimensional and color stability in long term use⁵⁻⁷. Water can be absorbed into the resins and act as plasticizer⁸. The unreacted monomer trap within the resins can also be released into the oral environment. The amount of the released monomer can be detected with HPLC technique. Calibration curve from the known concentration of the known standard monomer is used for calculation^{1,9-13}.

Commercial orthodontic adhesives have been reported an adverse effect to mouse and human fibroblast cells¹⁴⁻¹⁶. The amount and compositions of the eluted substances are the main factors for toxicity studies of the resin materials^{4,17-20}. Many researchers focused on the elutable type of residual monomers^{1,4,10-11,21}. Bisphenol A diglycidyl dimethacrylate (Bis-GMA) and triethylene glycol dimethacrylate (TEGDMA) are most monomers used as the resin matrices. Bis-GMA was reported to reduce the mouse fertility, the fertility rates of the female mouse, and also the number of viable fetuses²². TEGDMA has lower molecular mass and its unreacted molecule

exhibit cytotoxic, genotoxic, mutagenic, and allergenic effects²³. Moreover, some researchers also concern regarding the resins oestrogenicity effect of Bis-phenol-A²⁴, one of the most concerned monomer in the latest decade because it is able to interact with human estrogen receptor¹⁷. Even it was not incorporated in the dental resins formulations, there are some BPA as impurity once it is the raw material for bis component synthesis and it is a by-products resulting from degradation of adhesive resins¹⁸. It can act as a hormone which cause biological effects such as premature puberty in girls, ovarian cancer, or disruptive maturation of male reproductive organ¹⁰.

Most study have been focusing on the monomer elution of dental composite resins. There was a limit number of water sorption and solubility of the self-cure orthodontic adhesives. In the present study, water sorption, water solubility, and residual monomer elution will be investigated from three commercial orthodontic adhesives representative of self-cure, light-cure, and color-change light-cure for period of 1,3,5, and 7 d after initiation.

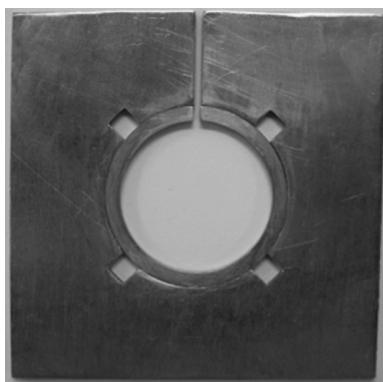
Materials and Methods

One self-cured; Unite (Unitek Corp., Monrovia, CA, USA, lot number HS5KH, exp 2019-12-28) and two light-cured orthodontic adhesives; Enlight (Ormco, Glendora, California, USA, lot number 740-0198, exp. 2019-11-28) and GrenGloo (Ormco, Glendora, California, USA, lot number 6167341, exp 2018-10-25) were used in this study. The adhesive compositions are as shown in Table 1. The specimen of 10 mm diameter and 1 mm thick cylindrical shaped, with a volume of 78.539 mm³ were prepared with the use of stainless steel split-mold in Figure 1 according to ISO 4049:2009 (ISO4049:2009)²⁵.

Table 1 The compositions from MSDS 26-29 of the three orthodontic adhesives used in this study.

Adhesive	Compositions	Cas #
Enlight (Light-cure)	Poly(oxy-1,2-ethanediyl), α , α' -[(1-methylethylidene)di-4,1-phenylene]bis[ω -[(2-methyl-1-oxo-2-propen-1-yl)oxy]- 10-30%,	41637-38-1
	3-(Trimethoxysilyl)propyl methacrylate 1-5%	2530-85-0
GrenGloo (Light-cure)	TEGDMA 5-10%,	109-16-0
	4,4'-methylenedi(cyclohexyl isocyanate) 1-5%,	5124-30-1
	Hydroxyethyl Methacrylate 1-5%,	868-77-9
	Polyol 1-5%,	-
	Poly(oxy-1,2-ethanediyl), α , α' -[(1-methylethylethylidene)di-4,1-phenylene]bis[ω -[(2-methyl-1-oxo-2propen-1-yl)oxy] 1-5%,	41637-38-1
	3-trimethoxysilylpropyl methacrylate 1-5%,	2530-85-0
	2,3-epoxypropyl methacrylate	106-912
	41637-38-1	
	Propylidynetrimehanol, ethoxylated, esters with acrylic acid	28961-43-5
	Ethoxylated trimethylolpropane triacrylate 0.1-1%,	72869-86-4
Diurethane dimethacrylate 0.1-1%,	162881-26-7	
phenyl bis(2,4,6-trimethylbenzoyl)-phosphine oxide 0.1-1%		
Unite (Chemical-cure)	<i>Primer:</i>	
	TEGDMA 70-80%,	109-16-0
	2,2'-(p-tolyimino)diethanol 5-15%,	3077-12-1
	Bis-GMA 5-15%,	1565-94-2
	3-methacryloxypropyltrimethoxysilane <5%,	2530-85-0
	Polymethyl Methacrylate <5%,	9011-14-7
	<i>Adhesive:</i>	
	Silane treated quartz 50-60%,	100402-78-6
	TEGDMA 15-25%,	109-16-0
	Bis-GMA 10-20%,	1565-94-2
Silane treated silica 5-10%,	68611-44-9	
Benzoylperoxide<2%,	94-36-0	
Dimethyl siloxane <2%	67762-90-7	

TEGDMA:Triethylene glycol demethacrylate, Bis-GMA:Bis-phenol A diglycidyl ether dimethacrylate,

**Figure 1** Mold used for preparation of water sorption specimens.

Water sorption and water solubility

Each adhesive specimen was individually polymerized with the use of the stainless steel mold (n=5). For chemically cured Unite, the primer was placed onto a glass slides. The adhesive paste was put into the mold placed on the primer-applied glass slide before mixing in order to homogenized the specimen. It is noted that, all of the tools used with the chemically cured must be freezed at -20°C for 1 hour to prevent pre-polymerization, including adhesive primer, adhesive paste, cover glass, mold, and plastic spatula. After packing into the mold, the specimen was then immediately clamped between the glass slides with 100 g load for 3 min before removed from the mold and placed in a 37°C desiccator. For Enlight and Grengloo, the adhesive was placed into the mold with plastic spatula between two glass slides and clamped with 100 g load for 3 min. Then, light-curing was done through the glass slides with overlapping technique as shown in the schematic steps in Figure 2 on the top and bottom of the specimen. The curing time for each section was 10 second through the glass slide with 0.25 mm thickness. The light curing device used in this study was

Bluephase G2 (Ivoclar Vivadent, Schaan, Liechtenstein) with an intensity of 1200 mW/cm². After removal from the mold, every specimen was kept in a silicagel-contained desiccator at 37°C for 22 h. Then, it was removed to a 23°C desiccator and reweighted every 24 h until constant weight was achieved. The constant weight was recorded as M₁. After that, the specimen was immersed in a tightly sealed vial of 10 ml 37°C distilled water for an interval time of 1,3,5, and 7 d. After finished the interval time of immersion, the specimen was carefully washed and gentle air blown before weighting and recorded as M₂. The specimen was then kept in a 23°C desiccator. The specimen was weighted daily until constant weight was achieved and recorded as M₃. The diameter and the thickness of the specimen were measured at five points and the volume (V) was calculated in cubic millimeters. The values of water sorption (W_{sp}) and solubility (W_{sl}) were calculated following formulae:

$$WSP = \frac{M_2 - M_3}{V}$$

$$WSL = \frac{M_1 - M_3}{V}$$

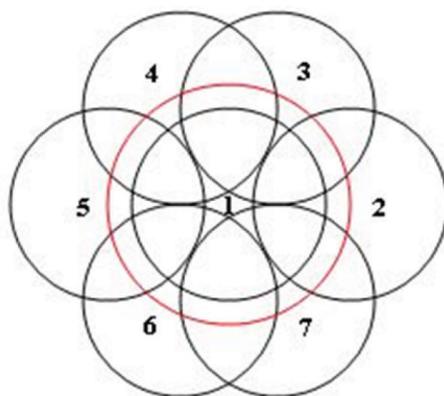


Figure 2 Schematic diagram of overlapping irradiation zones for the preparation of the water sorption specimens

Data were tested normality (Kolmogorov-Smirnov test) and equal variance (Levene's test). One-way ANOVA followed by Dunnett T3 to test differences between adhesive groups at the same time interval and at different time intervals of the same adhesive. Pearson's correlation coefficient was used to measure the degree of linear relationship between water sorption and water solubility. The statistical significance level was set at $\alpha = 0.05$. Statistical analysis was performed in SPSS.

Monomer elution

Each adhesive specimen prepared with the same method as explained above was used to determine the monomer elution. After polymerization, the specimen was removed from the mold and immediately immersed in 10 ml of 75% ethanol (75% ethanol and 25% distilled water) solution in a tightly-sealed glass vial at 37°C for the time interval of 1, 3, 5, and 7 d. After the immersion period, the whole medium was collected and kept in a tightly sealed vial before HPLC injection within a day.

Bisphenol A glycidyl dimethacrylate (Bis-GMA), Triethylene glycol dimethacrylate (TEGDMA), and Bisphenol A (BPA) concentration from the immersion medium were determined. The solutions were filtered with Nylon syringe filters, 0.22 μm \times 13 mm (Agela technologies, New York). The qualitative and quantitative analysis was performed by reversed-phase HPLC (D-7000) connected to a UV detector (L-7400) consisting of an autosampler (L-7200), a pump (L-2130) and a degasys (DG-2410) (Hitachi High Technologies America, Pleasanton, CA). HPLC conditions were as follows: 5 μl injection volume, equipped with a Luna C18 (5 μm) stainless steel column (4.6 X 150 mm), Phenomenex, Le Pecq, France). The mobile phase was a mixture of 30% water and 70% acetonitrile HPLC grade (Chromasolv; Hannover, Germany). The flow rate

was 1 ml/min and the injection volume was 5 μL . UV detection was performed at 205 nm.

Reference standard solutions of Bis-GMA (Esstech, Essington, PA), TEGDMA (Esstech, Essington, PA), and BPA (Sigma Aldrich, St Louis, MO) were used to produce stock solutions of 1,000 $\mu\text{g/ml}$ each. These stock solutions were diluted with 75% ethanol to produce the calibration solutions: 0.1, 1, 5, 10, 25, 50, and 100 $\mu\text{g/ml}$. The peak area for each monomer was determined and plotted versus concentration using linear regression analysis for BPA ($y=37.945x-3.0219$, $R^2=0.9999$), TEGDMA ($y=16.635x+3.6417$, $R^2=0.9997$), and Bis-GMA ($y=25.876x-8.4745$, $R^2=0.9999$). The amount of elution detected were calculated and reported into weight changed per volume (mm^3).

Data were tested normality (Kolmogorov-Smirnov test) and equal variance (Levene's test). One-way ANOVA followed by Tukey's to test differences between adhesive groups at the same time interval and at different time intervals of the same adhesive. The statistical significance level was set at $\alpha = 0.05$. Statistical analysis was performed in SPSS.

Results

Water Sorption

Water sorption of the three orthodontic adhesives used in this study are presented in Table 2. According to ISO 4049²⁵, they were calculated according to the equation given above, and reported in weight change per volume ($\mu\text{g/mm}^3$). However, only little differences in the weight changes between M_1 and M_3 , and M_2 and M_3 . In order to show the data, they were reported into the power of ($\times 10^{-2}$) for water sorption and ($\times 10^{-4}$) for water solubility.

Table 2 Mean (standard deviations) of water sorption ($\mu\text{g}/\text{mm}^3$) of commercial adhesives tested in this study after immersion in distilled water to 7 d.

Adhesive	Water sorption (SD) ($\times 10^{-2}$) ($\mu\text{g}/\text{mm}^3$)				Water solubility (SD) ($\times 10^{-4}$) ($\mu\text{g}/\text{mm}^3$)			
	D1	D3	D5	D7	D1	D3	D5	D7
Enlight	A	B	B	† B	a	c	c	ψ^a
	0.101(0.060)	0.297(0.136)	0.631(0.279)	0.772(0.256)	0.001(0.001)	0.001(0.001)	0.001(0.001)	3.073(0.072)
Grengloo	A	C	C	† B	a	b	b	ψ^a
	0.010(0.035)	0.010(0.035)	0.010(0.035)	0.813(0.126)	0.003(0.002)	0.010(0.004)	0.021(0.009)	3.368(0.149)
Unite	† A	A	A	A	ψ^a	a	a	b
	0.234(0.260)	0.974(0.166)	1.780(0.448)	1.932(0.482)	0.006(0.004)	0.026(0.004)	0.484(0.141)	2.906(0.203)

A,B,C ($P < 0.05$) different capital letter indicates a significant differences water sorption among the adhesives at the same time interval.

†($P < 0.05$) indicates a significant differences water sorption among the interval times of the same adhesive.

a,b,c ($P < 0.05$) different lower case letter indicates a significant differences water sorption among the adhesives at the same time interval.

ψ ($P < 0.05$) indicates a significant differences water sorption among the interval times of the same adhesive.

Bar line ($P \geq 0.05$) indicates similar results of the same adhesive among the interval times

Monomer Elution

All of the three monomer Bis-GMA, TEGDMA, and BPA were found from the immersion medium of the three commercial orthodontic adhesive used in this study except for Grengloo. Grengloo showed no Bis-GMA detected in its immersion medium. The HPLC chromatogram of the 7 d extraction medium of the three orthodontic adhesives and a mix standard of 100 $\mu\text{g}/\text{ml}$ were shown in Figure 3. The retention time of the three standard monomers were as follows; BPA (2.305 min), TEGDMA (3.165 min), and Bis-GMA (4.979 min), respectively.

Discussion

In this study, water sorption, solubility, and monomer elution of different three commercial

orthodontic adhesives were investigated at 1,3,5, and 7 d. One chemically cured (Unite), one light-cured (Enlight), and one light-cured with color changeable (Grengloo) were selected. Within the limitation of the study, water sorption and solubility were done in distilled water according to the ISO 4049:2009 specification²⁵. However, Bis-GMA could not elute with the use of distilled water or normal saline^{4,30}. Therefore, 75% ethanol was used in our elution test. In order to stimulate the specimen leachability and elution process, 75% ethanol was used as an immersion medium as recommended by US FDA³¹ to use as a food/oral simulating medium which relevant to the aggressiveness of the intraoral fluids. The time period for immersion has been reported to reach the saturation within 7-60 d³². Therefore, the maximum time of 7 d storage was used for the investigation in this study.

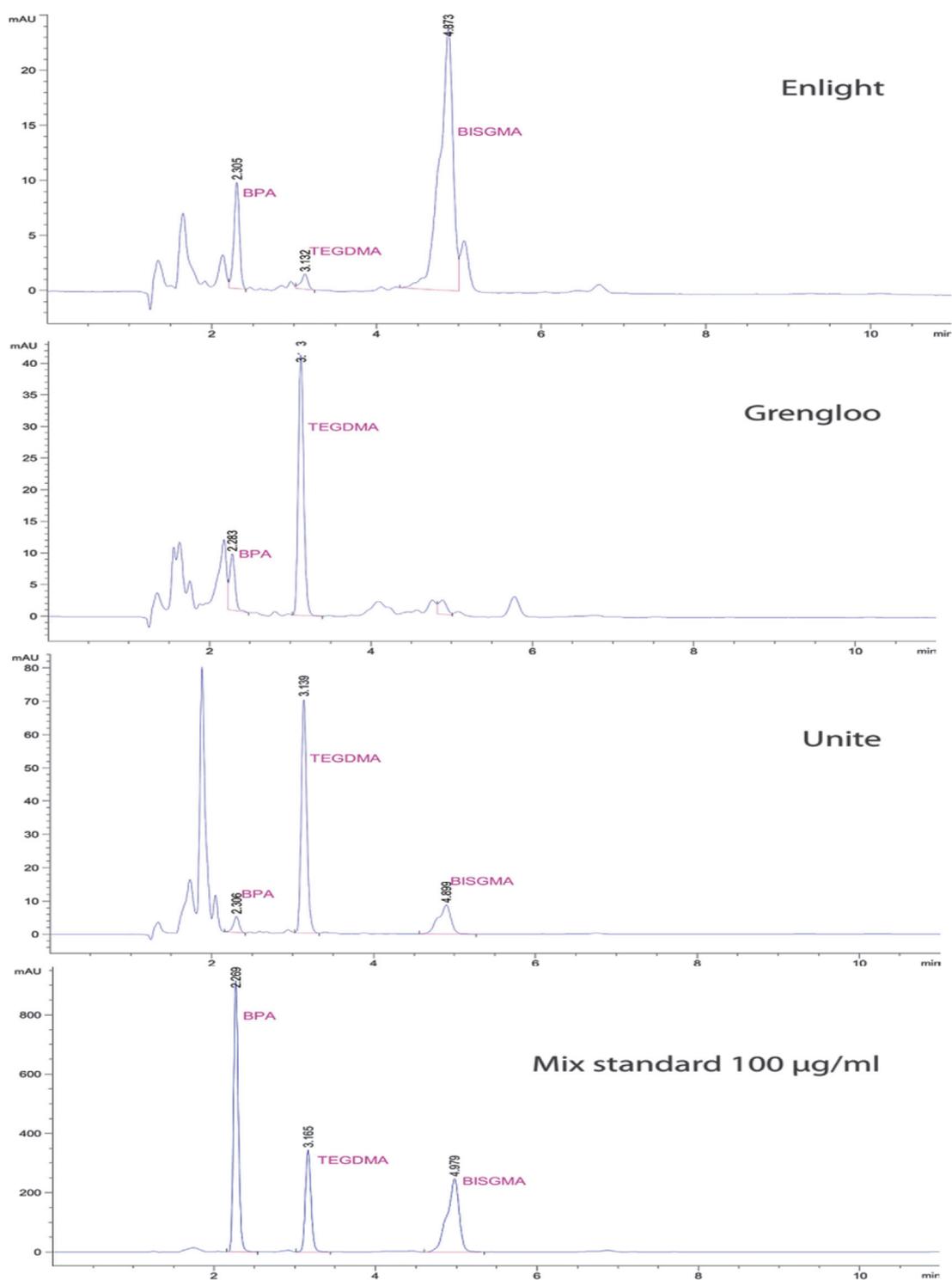


Figure 3 The HPLC chromatogram of the 7 d extraction medium from the three orthodontic adhesive specimens and a mix standard of 100 µg/ml.

In theory, there are two mechanisms of water sorption into the resins. First is the free volumetric theory, which molecule directly diffuse into the resin matrix by a diffusion-controlled process³³ via microvoids and the defects along the filler-matrix interfaces³². The second is from interaction of the solvent to the hydrophilic groups forming hydrogen bonds³⁴⁻³⁵. While solubility reflects the release amount of monomers oligomers, filler particles that can eluted by a solution or solvent and resulting in losing the weight⁸. Water sorption and solubility of the resin materials are normally affected by many factors. The most important factors are the material chemical compositions⁵⁻⁶, degree of conversion^{1,2,4}, and hydrophilicity with the solvent⁸.

In our study, the water sorption and solubility mean and SD of the three orthodontic adhesives were found in the range of 0.010×10^{-2} to 1.932×10^{-2} $\mu\text{g}/\text{mm}^3$ and 0.001×10^{-4} to 3.368×10^{-4} $\mu\text{g}/\text{mm}^3$, respectively. According to ISO 4049²⁵, the values should be less than $40 \mu\text{g}/\text{mm}^3$ for water sorption and $7.5 \mu\text{g}/\text{mm}^3$ for water solubility. These orthodontic adhesives had acceptable results not exceed the ISO standard. From Table 2, both water sorption and solubility increased with time for all adhesives. At 1 d, all adhesives had similar results ($p > 0.05$). The bar line also showed similar results among different time of the same adhesive ($p > 0.05$). Statistically significantly differences were found between at 1 d and 7 d of all cases ($p < 0.05$). However Unite showed significantly higher water sorption and solubility than Enlight and Grengloo for almost cases, except it had lower solubility at 7 d ($p < 0.05$). Pearson's correlation coefficient were found high correlation between water sorption and solubility ($R^2 = 0.988$).

The manufacturer's MSDS as shown in Table 1 gave us some information but not the exact percentage of each component. However, orthodontic adhesives normally contain high load of more than 60% fillers because of the consistency

property needed when apply onto the tooth surface. Some researchers reported a different in water sorption, solubility when compare the filled and unfilled resins^{5,38}. While, different size and shape filler loading was reported to have different water sorption and solubility³⁹. This filler inclusion might be the explanation of some weight loss from all three orthodontic adhesives used in our study. The specimen from water solubility test were desiccated until stable and found to change the weight until 7 d. After calculation by its volume of 78.539 mm^3 , water sorption and solubility were very little. In order to present the data, they were reported into the power of minus 2 for water sorption and the power of minus 4 for water solubility.

For HPLC test, preparation of the mix standard which combined the known concentration of Bis-GMA, TEGDMA, and BPA within a solution, BPA was the first monomer to leached out from HPLC and had less retention time as shown in Fig 3. Followed by TEGDMA, and Bis-GMA, respectively. HPLC chromatograms of the immersion medium from the three orthodontic adhesives showed that there were some components leached into the immersion medium at all time intervals. Not only the three monomers which are used as the reference standard in this study, but also some other components leached into the immersion medium which can be seen from the peaks at other retention time in the chromatograms. In order to specify quantitative and qualitative of the other peaks in chromatogram, the known concentration of that component must be used as a standard to create the calibration curve. Then the extraction medium contains that component can be calculated into concentration per volume.

After immersion, the solvent diffuses into the resin network and act as plasticizer. It would penetrate and separate the polymer chain

interactions. It is chemically degradation by hydrolysis. There were stresses occurred at the filler-matrix interface and form some microcracks⁵. The presence of porosity, voids, and cracks may also enhance transport of liquid into and out of the polymeric network resulting in an increase of sorption and solubility³⁶⁻³⁷. Unreacted monomer from incomplete polymerization which trapped within the resins can be eluted. The polymer become softening and weakening the polymer network and resulted in filler pull-out with elution of leachable moieties and degrade the mechanical properties^{8,39}. This process depend on the hydrophilicity (which is ranked by solubility parameters)². If the resin monomer has solubility parameter closer to the immersion medium, the monomer was reported to absorb and elute more⁴¹.

Bis-GMA were found only from Enlight and Unite in varied amount ($p < 0.05$). The quantity of water sorption and solubility, and varied amount of elution may come from undesirable and uncontrollable voids from specimen preparation which may caused air entrapment in the bulk materials, as it can be seen from the Unite which gave higher water sorption compared to Enlight and Grengloo. The chemically cured orthodontic Unite has two components which has to be mixed together to initiate the polymerization before use. Voids and porosities may result in stain susceptibility and discoloration⁷. This can be implied that the resin absorbs water and water penetrates into these little spaces before it is desiccated and returns to the original weight.

Hydrophilicity^{8,42} and the lower molecular size of TEGDMA may response for the significantly higher elution than the others, due to its molecules are smaller (lower molecular weight) and therefore eluted at a faster rate than bulky Bis-GMA molecules with two aromatic rings⁴². Moreover, compare to Enlight and Grengloo, TEGDMA was

corporate in the Unite primer up to 70-80% combined with 15-25% in its adhesive paste which was however more than TEGDMA in Grengloo composition. Grengloo contains only 5-10% as specified in their MSDS. Therefore, inclusion of higher TEGDMA in the composition of Unite, may responsible for the more amount of monomer found to be leached. Pearson's correlation coefficient were found high correlation between elution of TEGDMA with water sorption at 3 d and 5 d ($R^2 = 0.878, 0.872$) and with water solubility at 3 d ($R^2 = 0.832$). However, other elution and water sorption and solubility were found no correlation. In accordance with Sideridou et al., 2005 which reported no correlation between elution and water solubility⁴³.

BPA of Grengloo significantly increased with time ($p < 0.05$) but for Enlight and Unite, the BPA elution were varied as shown in Table 3. For Bis-GMA and TEGDMA of Enlight and Unite showed varied results with time. Some reserachers reported that there were no differences between elution of light-cure and chemical cure orthodontic adhesives⁴. In our study, Unite the chemically cured adhesive, which has two components to be mixed together had the most varied results. Mixing of the two components might be one reason for undesirable voids and air entrapment in the bulk materials as said above which leads to varied elution results.

From the study can indicate that although the water sorption and solubility, and elution are mainly depend on the resins compositions and properties, however the chemically cured adhesive may had an effect from preparation method. This might be the reason for limited number of chemically cured orthodontic adhesive study on water sorption and solubility. Moreover, care should be taken when selecting the materials for patients with allergic to specific monomer.

Table 3 The standard monomer Bis-GMA, TEGDMA, and BPA detected from immersion medium at 1,3,5, and 7 d of the three orthodontic adhesives used in this study ($\mu\text{g}/\text{mm}^3$).

Adhesives	Monomer	Elution (SD) ($\mu\text{g}/\text{mm}^3$)			
		1 D	3 D	5 D	7 D
Enlight	Bis-GMA	0.347(0.021)	1.303(0.008)	0.571(0.039)	1.299(0.037)
	TEGDMA	0.116(0.001)	0.036(0.001)	0.047(0.001)	0.031(0.003)
	BPA	0.014(0.001)	0.072(0.001)	0.060(0.001)	0.142(0.001)
Grenghoo	Bis-GMA	n.d	n.d	n.d	n.d
	TEGDMA	0.588(0.002)	1.295(0.006)	0.293(0.004)	1.459(0.013)
	BPA	0.050(0.001)	0.120(0.002)	0.140(0.001)	0.127(0.001)
Unite	Bis-GMA	0.346(0.050)	1.755(0.026)	0.097(0.004)	0.433(0.005)
	TEGDMA	10.149(0.094)	16.463(0.100)	0.604(0.001)	2.524(0.004)
	BPA	0.070(0.001)	0.180(0.003)	0.021(0.001)	0.068(0.002)

n.d. = not detected

† ($P \geq 0.05$) indicates similar Bis-GMA results of the same adhesive among the interval times.

‡ ($P \geq 0.05$) indicates similar BPA results of the same adhesive among the interval times

Conclusions

1. Water sorption and solubility a chemically-cured and two light-cured adhesives were all gradually increase with storage time.

2. All cases of water sorption, solubility, and elution were significantly different between 1 d and 7 d ($p < 0.05$)

3. Water sorption has high correlation with water solubility ($R^2 = 0.988$).

4. No correlation were found from neither water sorption nor solubility to elution of Bis-GMA and BPA.

5. TEGDMA has correlation to the water sorption and solubility at 3 d ($R^2 = 0.754$) and ($R^2 = 0.878$)

6. The amount of water sorption and solubility found in this study were less than specified in ISO 4049

7. Dominant monomer seems to elute more. Elution capability depends on the solubility parameter of the monomer and the solvent

Acknowledgement

The author had no conflict of interest and would like to thank staffs, Faculty of Dentistry, and Faculty of Public Health, Mahidol University for facilities supporting throughout this project.

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