Monomer Release from Nanofilled and Microhybrid Dental Composites after Bleaching

Masumeh Hasani Tabatabaei¹, Sakineh Arami², Maryam Ghavam³, Asieh Rezaii⁴

¹Associate Professor, Dental Research Center Dentistry Research Institute, Department of Operative Dentistry, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran
²Assistant Professor, Department of Operative Dentistry, School of Dentistry Tehran University of Medical Sciences, Tehran, Iran
³Associate Professor, Dental Research Center Dentistry Research Institute, Tehran University of Medical Sciences, Tehran, Iran
⁴Dentist

Abstract

Objective: The aim of this study was to assess the effect of bleaching on elution of monomers from nanofilled and microhybrid composites.

Materials and Methods: 80 samples (5mm diameter and 3mm thickness) of each composite were prepared. After curing, half of them were randomly polished. Each group was divided into 8 subgroups and immersed in water or 10%, 20% and 30% H2O2 for 3 or 8 hours. Eluted Bis-GMA (Bis-phenol A Glycidyl Dimethacrylate), TEGDMA (Triethyleneglycol Dimethacrylate), UDMA (Urethane Dimethacrylate) and BisEMA (Bis-phenol A ethoxylate Dimethacrylate) were quantified by high performance liquid chromatography and the results were analyzed by univariate ANOVA and t-test (P<0.05).

Results: Bleaching significantly increased the overall release of monomers (P<0.001); TEGDMA was released more than Bis-GMA (P<0.001). Supreme released more TEGDMA compared to Z250 (P<0.001). Bleaching increased the release of this monomer (P<0.001). Increasing both the concentration of H2O2, and the immersion time, increased the release of TEGDMA (P<0.001). Polishing had no effect on release of this monomer (P=0.952). Supreme released more Bis-GMA than Z250 (P=0.000). The more concentrated H2O2 caused more elution of Bis-GMA (P=0.003); while the effect of immersion time was not significant (P=0.824). Polishing increased the release of Bis-GMA (P=0.001). Neither the type of composite nor Bleaching had any effect on release of UDMA (P=0.972) and (P=0.811) respectively. Immersion duration increased the release of UDMA (P=0.002), as well as polishing (P=0.024).

Conclusion: Bleaching increased the release of monomers. Nanofilled composites released more monomer than the microfilled.

Key words: Monomer elution; Dental composites; Chromatography; Bleaching

INTRODUCTION

Dental composite resins are used in most dental treatments as restorative or adhesive materials. Besides direct fillings, these resins are also used as cements, dentin adhesives and luting agents for inlays, crowns, orthodontic brackets, and veneers [1, 2]. Other than UDMA and Bis-GMA, high quantities of TEGDMA as the diluents of monomer and Hema, a hydrophilic monomer, are common...
components of resin composites [2-4]. Despite being considered highly stable structures, dental composites are susceptible to degradation due to the incomplete polymerization and the influence of the aqueous oral environment [5]. It has been demonstrated that unconverted monomers can be released from the resin composites into adjacent aqueous environment [6-9]. These monomers can be released into saliva and contact the mucosal tissues, and even reach the pulp via dentinal tubules [10]. HEMA and TEGDMA are the main monomers released from resin-based materials [11]. Elution of monomers from composites has consequences like reduced mechanical properties and increased biological hazards, thus it is important to study the pattern of monomer release in different clinical situations. Polydorou et al. investigated the elution of monomers from different composites and concluded that the release of monomers from a nanohybrid and a chemically-cured composite was significantly higher than Ormocer [12]. Tooth Bleaching is another part of esthetic dentistry. Different concentrations of hydrogen peroxide have been used in bleaching procedures [13]. Studies concerning the interaction between composite restorations and bleaching materials have extensively evaluated the bond strength of adhesives to enamel and dentin after bleaching [14, 15], effect of bleaching agents on surface texture, hardness and roughness [16-19], and color and microleakage of dental composites [20]. There are few studies on the effect of bleaching agents on release of monomers from composites. Recently, Polydorou et al. studied the effect of bleaching on the elution of monomers from an Ormocer and a nanohybrid composite and reported a reduction in monomer release after bleaching [21]. Patients seeking bleaching treatment may have teeth restored with different types of composites. Interaction of bleaching materials with resin composites in the oral cavity is a serious concern because oxidative properties of active agents in bleaching materials can have side effects on resin composites [17-20]. Understanding the behavior of monomer release and monitoring the leachable components are crucial to clear the degradation process of polymer-based materials in different clinical procedures. The aim of this study was to detect and quantify the main monomers released from polished or unpolished microhybrid and nanofilled composites after different storage times in different concentrations of hydrogen peroxide, using high performance liquid chromatography (HPLC). The quantities of monomers released were the dependent variables, while the types of composite resins, polishing, H2O2 concentration and duration of immersion were the independent variables.

MATERIALS AND METHODS
Table 1 shows the components of composites used in the study. First 80 disk-shaped samples of each composite (5x3 mm) were prepared in stainless steel molds.

| Composite       | Manufacturer | Organic matrix                  | Filler              | Particle size |
|-----------------|--------------|---------------------------------|---------------------|---------------|
| Filtek TM Z250  | 3M ESPE      | BisGMA/UDMA TEGDMA bisEMA      | Zirconia/silica     | 0.01-3.5nm    |
|                 |              |                                 | (60%)               |               |
| Filtek TM Supreme | 3M ESPE    | BisGMA/UDMA TEGDMA bisEMA     | Zirconia/silica     | 5-20 nm       |
|                 |              |                                 | (59.5%)             |               |
A Mylar strip was placed on the top of the composite and the polymerization was completed with a light-curing unit (Ultralume 2, LED, Ultradent, USA), with 600 Mw/cm² output, controlled by a radiometer (Bisco, USA). The manufacturer’s instructions were followed for each material.

Randomly, half of the cured composites were polished by medium and fine grit polishing disks (OptiDisk, Kerr Howe, USA).

All of the samples were randomly immersed in 2 cc of distilled water (as controls), or 10%, 20% and 30% H2O2, for 3 to 8 hours at room temperature. Table 2 summarizes the studied groups.

Glass tubes used for immersion of the samples were completely sealed by paraffin and were covered by aluminum foil to keep the samples away from light. After the immersion procedure, the tubes were refrigerated until HPLC analysis. Bis-GMA, BisEMA and UDMA with 100% purity and TEGDMA with 90% purity were used to create calibration curves. Table 3 shows the monomers used for this purpose. The released monomers were detected and quantified as microgram/liter. Effect of the type of composite, polishing, concentration of H2O2 and immersion time on release of each monomer was evaluated and analyzed using Univariate ANOVA.

### Table 2. Detail of the subgroups tested

| Composite Type | Nanofilled | Microhybrid |
|----------------|------------|-------------|
|                | Polished   | Unpolished  | Polished   | Unpolished |
| Surface        |            |            |            |            |
| Medium Control | 10% H2O2   | 20% H2O2   | 30% H2O2   | 10% H2O2   |
| 3% H2O2        | 3% H2O2    | 3% H2O2    | 3% H2O2    | 3% H2O2    |
| Time (hours)   | 3          | 8          | 3          | 8          |

### Table 3. Standard Monomers used for HPLC

| Monomer                              | Company                  |
|--------------------------------------|--------------------------|
| Bisphenol A Glycidyl Dimethacrylate (Bis-GMA) | (Aldrich - USA)         |
| Bisphenol A ethoxylate Dimethacrylate (Bis-EMA) | (Aldrich - USA)         |
| Urethane Dimethacrylate (UDMA)        | (Aldrich - USA)         |
| Triethyleneglycol Dimethacrylate (TEGDMA) | (Fluka Germany) |
Since the three-way and two-way interactions were significant in the subgroups, independent sample t-test was used. Bonferroni’s correction method was used to counteract the problem of multiple comparisons. P<0.05 was considered the limit of significance.

RESULTS
Tables 4-6 show the effect of independent variables on release of Bis-GMA, TEGDMA and UDMA, respectively. As can be observed, the interactions were significant. Table 7 shows the mean and SD of Bis-GMA released from Supreme and Z250. Table 8 depicts the mean and SD of TEGDMA released from Supreme and Z250. Bleaching significantly increased the overall release of monomers (P<0.001), while TEGDMA was released more than Bis-GMA (P<0.001). The effect of independent variables on release of monomers is summarized as follows:

**Bis-GMA:**
Supreme released more Bis-GMA than Z250 (P=0.000). The more concentrated H2O2 caused more elution of Bis-GMA (P= 0.003); while the effect of immersion time was not significant (P=0.824). It was observed that polishing significantly increased the release of Bis-GMA (P=0.001).

**TEGDMA:**
TEGDMA was released significantly more in Supreme composite compared to Z250 (P<0.001). Bleaching significantly increased the release of this monomer (P<0.001). Increasing both the concentration of H2O2, and the immersion time, increased the release of TEGDMA (P<0.001). But polishing had no effect on release of this monomer. (P=0.952).

**UDMA:**
The type of composite had no effect on release of UDMA (P=0.972). Bleaching was also ineffective (P=0.811). Immersion duration increased the release of UDMA (P=0.002). Polishing increased the release of this monomer (P=0.024).

**BisEMA:**
No evidence of BisEMA release was observed in this study

DISCUSSION
The most frequently used substances for bleaching vital teeth are 10% to 37% carbamide peroxide, and 1.5% to 38% hydrogen peroxide; the more concentrated products are used professionally in the dental office [22]. The H2O2 concentrations used in the present study are among the usual concentrations applied in clinical bleaching procedures. There is controversy about the impact of low concentrated 10%–16% carbamide peroxide gels or 35% hydrogen peroxide on surface micro-hardness of restorative composite materials [17-19]. Such wide variations in data suggest that some tooth colored restorative materials may be more susceptible to alterations caused by some bleaching agents. This is why in this study composites with the same matrix composition were used. The detection method used was HPLC; which is a valuable and popular method of analysis, not limited by the volatility or stability of the sample compound; many researchers have used this method in dentistry [23-25]. The results confirmed that TEGDMA was released significantly more than Bis-GMA. This observation was in agreement with Nathanson et al [26], who showed that smaller molecules are released faster and more than the larger ones because of their mobility. TEGDMA is added to Bis-GMA to decrease viscosity of the composition. Tabatabaee et al. showed that TEGDMA was released more than Bis-GMA from both nanofilled and flowable composites cured with either halogen or LED curing units [27]. The greater release of Bis-GMA and TEGDMA in higher concentrations of H2O2 was confirmed by Durner et al,
### Table 4. Analysis of variance of BisGMA released in the tested media

| Source                        | Type III Sum of Squares | df | Mean Square | F     | Sig. |
|-------------------------------|-------------------------|----|-------------|-------|------|
| Corrected Model               | 20.398(a)               | 31 | .658        | 5.159 | .000 |
| Intercept                     | 74.377                  | 1  | 74.377      | 583.113 | .000 |
| CONCENTR                      | 2.758                   | 3  | .919        | 7.208 | .000 |
| TIME                          | 6.383E-03               | 1  | 6.383E-03   | .050  | .824 |
| COMPOSIT                      | 1.190                   | 1  | 1.190       | 9.329 | .003 |
| POLISH                        | 1.496                   | 1  | 1.496       | 11.726 | .001 |
| CONCENTR * TIME               | 1.270                   | 3  | .423        | 3.320 | .256 |
| CONCENTR * COMPOSIT           | .513                    | 3  | .171        | 1.342 | .268 |
| TIME * COMPOSIT               | .203                    | 1  | .203        | 1.590 | .212 |
| CONCENTR * TIME * COMPOSIT    | 1.074                   | 3  | .358        | 2.808 | .046 |
| CONCENTR * POLISH             | 5.997                   | 3  | 1.999       | 15.672 | .000 |
| TIME * POLISH                 | .510                    | 1  | .510        | 4.002 | .049 |
| CONCENTR * TIME * POLISH      | .163                    | 3  | 5.441E-02   | .427  | .735 |
| COMPOSIT * POLISH             | 4.634E-02               | 1  | 4.634E-02   | .363  | .549 |
| CONCENTR * COMPOSIT * POLISH  | 1.897                   | 3  | .632        | 4.958 | .004 |
| TIME * COMPOSIT * POLISH      | 9.548E-02               | 1  | 9.548E-02   | .749  | .390 |
| CONCENTR * TIME * COMPOSIT * POLISH | .675          | 3  | .225        | 1.763 | .162 |
| Error                         | 8.801                   | 69 | .128        |       |      |
| Total                         | 103.910                 | 101|             |       |      |
| Corrected Total               | 29.200                  | 100|             |       |      |

### Table 5. Analysis of variance of TEGDMA released in the tested media

| Source                        | Type III Sum of Squares | Df | Mean Square | F     | Sig. |
|-------------------------------|-------------------------|----|-------------|-------|------|
| Corrected Model               | 3.327(a)                | 31 | .107        | 20.294 | .000 |
| Intercept                     | 20.499                  | 1  | 20.499      | 3876.261 | .000 |
| CONCENTR                      | .197                    | 3  | 6.580E-02   | 12.442 | .000 |
| TIME                          | .584                    | 1  | .584        | 110.412 | .000 |
| COMPOSIT                      | .659                    | 1  | .659        | 124.704 | .000 |
| POLISH                        | 1.906E-05               | 1  | 1.906E-05   | .004  | .952 |
| CONCENTR * TIME               | .283                    | 3  | 4.929E-02   | 17.829 | .000 |
| CONCENTR * COMPOSIT           | 8.154E-02               | 3  | 2.718E-02   | 5.140  | .003 |
| TIME * COMPOSIT               | 5.147E-02               | 1  | 5.147E-02   | 9.732  | .003 |
| CONCENTR * TIME * COMPOSIT    | 6.027E-02               | 3  | 2.009E-02   | 3.799  | .014 |
| CONCENTR * POLISH             | .201                    | 3  | 6.711E-02   | 12.689 | .000 |
| TIME * POLISH                 | 4.476E-02               | 1  | 4.476E-02   | 8.464  | .005 |
| CONCENTR * TIME * POLISH      | .111                    | 3  | 3.712E-02   | 7.020  | .000 |
| COMPOSIT * POLISH             | 4.150E-02               | 1  | 4.150E-02   | 7.848  | .007 |
| CONCENTR * COMPOSIT * POLISH  | .144                    | 3  | 4.799E-02   | 9.074  | .000 |
| TIME * COMPOSIT * POLISH      | 3.563E-03               | 1  | 3.563E-03   | .674   | .415 |
| CONCENTR * TIME * COMPOSiT * POLISH | 9.470E-02          | 3  | 3.157E-02   | 5.969  | .001 |
| Error                         | .365                    | 69 | 5.288E-03   |       |      |
| Total                         | 23.266                  | 101|             |       |      |
| Corrected Total               | 3.692                   | 100|             |       |      |
who reported that hydrogen peroxide could affect the three dimensional polymer network of composites, resulting in more monomer release [28]. Effect of different concentrations of H2O2 showed that the greater concentration resulted in greater release of both Bis-GMA and TEGDMA.

This can be interpreted as a positive relation between the presence of H2O2 and possibility of monomer release.

This observation did not confirm the results obtained by Polydorou et al. who studied the effect of 38% hydrogen peroxide for 45 min and 15% carbamide peroxide for 56h, on release of monomers from two different resin composites, a nanohybrid and an ormocer.

They concluded that bleaching agents reduced the amount of the monomers released from the two composite materials [21].

It should be mentioned that in the study conducted by Polydorou et al, after exposure to bleaching substance, the composite samples were washed and transferred to ethanol as the holding medium; therefore, some of the leached monomers may have been washed away. This may justify the different results, since in our study the bleaching medium was analyzed for monomer elution after removal of the composites. Polymerization conditions and the holding medium may affect the amount and type of released monomers. Moharamzade et al. used distilled water, saline solution, artificial saliva, serum-free culture medium, and culture medium with 10% fetal calf serum to extract monomers from different composites and concluded that the type of extraction medium may have significant effect on monomer release [25].

Table 6. Analysis of variance of UDMA released in the tested media

| Source                              | Type III Sum of Squares | Df | Mean Square | F     | Sig. |
|-------------------------------------|-------------------------|----|-------------|-------|------|
| Corrected Model                     | 98.616(a)               | 31 | 3.181       | 1.837 | .019 |
| Intercept                           | 193.178                 | 1  | 193.178     | 111.550 | .000 |
| CONCENTR                            | 1.664                   | 3  | .555        | .320  | .811 |
| TIME                                | 18.235                  | 1  | 18.235      | 10.530 | .002 |
| COMPOSIT                            | 2.207E-03               | 1  | 2.207E-03   | .001  | .972 |
| POLISH                              | 9.178                   | 1  | 9.178       | 5.300 | .024 |
| CONCENTR * TIME                     | 23.429                  | 3  | 7.810       | 4.510 | .060 |
| CONCENTR * COMPOSIT                 | 5.900                   | 3  | 1.967       | 1.136 | .341 |
| TIME * COMPOSIT                     | 1.073                   | 1  | 1.073       | .619  | .434 |
| CONCENTR * TIME * COMPOSIT          | 1.303                   | 3  | .434        | .251  | .860 |
| CONCENTR * POLISH                   | 1.241                   | 3  | .414        | .239  | .869 |
| TIME * POLISH                       | 3.048                   | 1  | 3.048       | 1.760 | .189 |
| COMPOSIT * POLISH                   | 13.672                  | 3  | 4.557       | 2.632 | .057 |
| CONCENTR * COMPOSIT * POLISH        | .844                    | 1  | .844        | .487  | .488 |
| TIME * COMPOSIT * POLISH            | 1.610E-02               | 1  | 1.610E-02   | .009  | .923 |
| CONCENTR * TIME * COMPOSIT * POLISH | 5.557                   | 3  | 1.852       | 1.070 | .368 |
| Error                               | 119.491                 | 69 | 1.732       |       |      |
| Total                               | 439.284                 | 101|             |       |      |
| Corrected Total                     | 218.107                 | 100|             |       |      |
The other explanation for these different results may be the difference in bleaching material, duration of immersion and type of the composites. Available information on the effect of bleaching medium on monomer elution is rare. Synergistic toxic effect of TEGDMA and H2O2 has been reported though the exact mechanism of this effect is not clear [29].

One possible explanation may be the softening effect of bleaching agent on composites which has been reported by Hanning et al, [30] and Basting et al [31]. However, other studies have not proven this [16, 19]. It seems that type and concentration of the bleaching material, time of immersion and the type of composite play key roles in this regard [19].

Table 7. Mean and SD of Bis GMA released in the tested media

|        | Surface   | Medium   | Time | Mean  | SD    |
|--------|-----------|----------|------|-------|-------|
| Z250   | unpolished| Control  | 3.00 | .75676| .655376|
| Supreme|           |          |      | .75328| .652364|
| Z250   | Polished  |          | 8.00 | .76056| .658696|
| Supreme|           |          |      | .75961| .657874|
| Z250   | unpolished| H2O2 (10 %) | 3.00 | .00000| .00000|
| Supreme|           |          |      | .00000| .00000|
| Z250   | Polished  |          | 8.00 | .00000| .00000|
| Supreme|           |          |      | .75961| .657975|
| Z250   | Polished  |          |      | 1.13509| .001264|
| Supreme|           |          |      | 1.18082| .045475|
| Z250   | unpolished| H2O2 (20 %) | 3.00 | .00000| .00000|
| Supreme|           |          |      | 1.16634| .001575|
| Z250   | Polished  |          |      | 1.14637| .010403|
| Supreme|           |          |      | 1.16755| .014087|
| Z250   | unpolished|          | 8.00 | .00000| .00000|
| Supreme|           |          |      | .77226| .668812|
| Z250   | Polished  |          |      | 1.15649| .019880|
| Supreme|           |          |      | 1.17798| .006295|
| Supreme|           |          |      | 1.20520| .005353|
| Z250   | unpolished| H2O2 (30 %) | 3.00 | 1.44932| .101309|
| Supreme|           |          |      | 1.23070| .116244|
| Z250   | Polished  |          |      | 1.15902| .032184|
| Supreme|           |          |      | 1.21845| .013443|
| Z250   | unpolished|          | 8.00 | 1.19251| .015668|
| Supreme|           |          |      | 1.22919| .055360|
| Z250   | Polished  |          |      | .00000| .00000|
| Supreme|           |          |      | 1.24942| .003041|
The higher concentration of H2O2 and the more immersion time in our study caused more monomer release. Since bleaching can both soften and roughen the composite surface, it is highly possible that it affects monomer release from composite restorations and thus affects the biocompatibility of the resins. The effect of polishing on monomer release was another issue studied in this research.

It is documented that polymerized composite under the Mylar sheet has a surface layer rich in low molecular weight monomers [32, 33]. During immersion in extracting medium, these smaller monomers are readily released. Removal of this layer by polishing may lead to less release of TEGDMA from polished samples. However, more research is needed in this regard.

| Composite | Surface | Medium    | Time | Mean  | SD    |
|-----------|---------|-----------|------|-------|-------|
| Z250      | unpolished | Control   | 3.00 | .47963 | .026763 |
| Supreme   |          |           |      | .58361 | .061515 |
| Z250      | Polished | H2O2 (10 %) | 3.00 | .44729 | .010293 |
| Supreme   |          |           |      | .48774 | .010883 |
| Z250      | unpolished | H2O2 (10 %) | 8.00 | .50918 | .020948 |
| Supreme   |          |           |      | .71371 | .141846 |
| Z250      | Polished | H2O2 (20 %) | 3.00 | .44909 | .007751 |
| Supreme   |          |           |      | .50351 | .019043 |
| Z250      | unpolished | H2O2 (30 %) | 3.00 | .00000 | .00000 |
| Supreme   |          |           |      | .46103 | .033444 |
| Z250      | Polished | H2O2 (30 %) | 3.00 | .12097 | .011218 |
| Supreme   |          |           |      | .48126 | .012570 |
| Z250      | unpolished | H2O2 (30 %) | 8.00 | .42477 | .003730 |
| Supreme   |          |           |      | .47171 | .014885 |
| Z250      | Polished | H2O2 (30 %) | 8.00 | .44990 | .010186 |
| Supreme   |          |           |      | .49820 | .006123 |
| Z250      | unpolished | H2O2 (30 %) | 8.00 | .125934 | .027321 |
| Supreme   |          |           |      | .55649 | .027321 |
| Z250      | Polished | H2O2 (30 %) | 8.00 | .00000 | .00000 |
| Supreme   |          |           |      | .46636 | .027863 |
| Z250      | unpolished | H2O2 (30 %) | 8.00 | .54252 | .019238 |
| Supreme   |          |           |      | .79309 | .125934 |
| Z250      | Polished | H2O2 (30 %) | 8.00 | .55234 | .022887 |
| Supreme   |          |           |      | .67821 | .106796 |
On the other hand, the results showed that nanofilled composite leached more TEGDMA than microhybrid composite. Da Silva et al. have reported that nanofilled composites may present higher degradation in the oral environment than hybrid ones [34]. This happens as the result of water sorption which leads to monomer elution [34, 35]. According to the manufacturer, composites tested in this study have the same polymeric matrix; thus, the size and arrangement of filler particles can be responsible for the significant differences observed in TEGDMA and Bis-GMA release. The sorption phenomenon in resin composites is mainly dependent on the hydrophilicity of their polymeric matrices [36]. In addition, the theoretically larger total surface area of nanofiller particles allows more water to accumulate at the filler particle-polymeric matrix interfaces, thus increasing the water sorption [9]. According to Santos et al, water accumulated at the aggregated zirconium/silica cluster filler-organic matrix interface in the nanofilled composite can create paths for water diffusion towards the inside of aggregates, where microvoids are probably present, due to lack of 5-20 nm-sized primary particles being impregnated in the polymeric matrix [37]. Part of the absorbed water in composites diffuses through the network and is trapped in polymer nano-voids; therefore the total void volume in the polymer network dictates the amount of absorbed water [34].

Initially, water sorption causes polymer softening as a result of reducing the frictional forces between the polymer chains [38]. After relaxation process, the unreacted monomers trapped in the polymer network are released at a rate controlled by the polymer's swelling and relaxation capacity [25]. It is clear that the more water absorbed, the more components leach out of resin composites [39, 40]. This phenomenon possibly explains the greater release of monomers from nanofilled composite in this study.

CONCLUSION
In the present study, H2O2 was applied according to common bleaching procedures. Taken together, TEGDMA was the main monomer released in this study and bleaching increased its release. Potential systemic adverse effects caused by this molecule and reduced mechanical and chemical properties of composite restorations after contact with bleaching materials must be addressed in treatment planning.

REFERENCES
1- Van Meerbeek B, Perdigão J, Lambrechts P, Vanherle G. The clinical performance of adhesives. J Dent. 1998 Jan;26(1):1-20.
2- Ruyter IE, Sjøvik IJ. Composition of Dental Resin and Composite Materials. Acta Odontologica 1981; 39: 133-146.
3- Peutzfeldt A. Resin composites in dentistry: the monomer systems. Eur J Oral Sci 1997; 105:97-11.
4- Asmussen E, Peutzfeldt A. Influence of UEDMA, BISGMA and TEGDMA on selected mechanical properties of experimental resin composites. Dent Mater 1998; 14:51-6.
5- Oysaed H, Ruyter IE. Water sorption and filler characteristics of composites for use in posterior teeth. J Dent Res 1986; 65:1315-8.
6- Gerzina TM, Hume WR. Effect of dentine on release of TEGDMA from resin composite in vitro. J Oral Rehabil 1994; 21: 463 – 468.
7- Ortengren U, Wellendorf H, Karlsson S, Ruyter IE. Water sorption and solubility of dental composites and identification of monomers released in an aqueous environment. J Oral Rehabil 2001;28(12): 1106-15.
8- Santerre JP, Shajii L, Leung BW. Relation of dental composite formulations to their degradation and the release of hydrolyzed polymeric-resin-derived products. Crit Rev Oral Biol Med 2001;12:136-51.
9- Ferracane J. Hygroscopic and hydrolytic effects in dental polymer networks. Dent Mater 2006; 22:211-222.
10- Ferracane JL. Elution of leachable components from composites. J Oral Rehabil 1994; 21:441-52.
11- Kaga M, Noda M, Ferracane JL, Nakamura W, Oguchi H, Sano H. The in vitro cytotoxicity of eluates from dentin bonding resins and their effect on tyrosine phosphorylation of L929 cells. Dent Mater 2001;17:333-9.
12- Polydorou O, König A, Hellwig E, Kümmerer K Long-term release of monomers from modern dental-composite materials. Eur J Oral Sci 2009;117:68-75.
13- Nathanson D, Parra C. Bleaching vital teeth: A review and clinical study. Compend cont in Educ Dent 1987; 8: 490 – 497.
14- Elkhatib H, Nakajima M, Hiraishi N, Kitasako Y, Tagami J, Nomura S. Surface PH and bond strength of a self-etching primer/adhesive system to intracoronal dentin after application of hydrogen peroxide bleach with sodium perborate. Oper Dent 2003; 28: 591 – 597.
15- Shinohara MS, Peris AR, Pimenta LA, Ambrosano GM. Shear bond strength evaluation of composite resin on enamel and dentin after nonvital bleaching. J Esthet Restor Dent 2005;17:22-9.
16- Polydorou O, Hellwig E, Auschill TM. The effect of different bleaching agents on the surface texture of restorative materials. Oper Dent 2006; 31:473-80.
17- Gurgan S, Yalcin F. The effect of 2 different bleaching regimes on the surface roughness and hardness of tooth-colored restorative materials. Quintessence Int 2007 ;38:e83-7.
18- Moraes RR, Marimon JL, Schneider LF, Correr Sobrinho L, Camacho GB, Bueno M. Carbamide peroxide bleaching agents: effects on surface roughness of enamel, composite and porcelain Clin Oral Investig 2006;10:23-8.
19- Campos I, Briso AL, Pimenta LA, Ambrosano G. Effects of bleaching with carbamide peroxide gels on microhardness of restoration materials. J Esthet Restor Dent 2003; 15:175-82.
20- Hubbezoglu I, Akaoglu B, Dogan A, Keskien S, Bolayir G, Ozcelik S, Dogan OM. Effect of bleaching on color change and refractive index of dental composite resins. Dent Mater J 2008 ;27:105-16.
21- Polydorou O, Beiter J, König A, Hellwig E, Kümmerer K. Effect of bleaching on the elution of monomers from modern dental composite materials. Dent Mater 2009; 25:254-60.
22- Michida SM, Passos SP, Marimoto AR, Garakis MC, de Araújo MA. Intrapulpal temperature variation during bleaching with various activation mechanisms. J Appl Oral Sci 2009;17(5):436-9.
23- Zhang Y, Xu J. Effect of immersion in various media on the sorption, solubility, elution of unreacted monomers, and flexural properties of two model dental composite compositions. J Mater Sci Mater Med 2008;19:2477-83.
24- Sideridou ID, Achilias DS. Elution study of unreacted Bis-GMA, TEGDMA, UDMA and BisEMA from light-cured dental resins and resin composites using HPLC. J Biomed Mater Res B Appl Biomater 2005;74:617-26.
25- Moharamzade K, VanNoort R, Brook IM, Scutt AM. HPLC analysis of components released from dental composites with different resin composition using different extraction media. J Mater Med 2007;18:133-137.
26- Nathanson D, Lertpitayakun P. In vitro Elution of leachable components from dental sealants. JADA 1997; 128: 1517 – 1523.
27- Tabatabae MH, Mahdavi H, Zandi S, Kharrazi MJ. HPLC analysis of eluted monomers from two composite resins cured with LED and halogen curing lights. J Biomed Mater Res B Appl Biomater 2008; 26: 145.
28- Durner J, Stojanovic M, Urcan E, Spahl W, Haertel U, Hickel R, et al. Effect of hydrogen peroxide on the three-dimensional polymer network in composites. Dent Mater 2011
29- Franz-Xaver R, Jürgen D, Kai K, Matthias F, Norbert K, Markus S, et al. Synergistic effects of H2O2 with components of dental restorative materials on gluconeogenesis in rat kidney tubules. Biomaterials 2003;24:1909-16.

30- Hanning C, Duong S, Becker K, Brunner E, Kahler E, Attin T. Effect of bleaching on subsurface micro-hardness of composite and a polyacid modified composite. Dent Mater 2007;23:198-203.

31- Basting RT, Fernandéz C F Y, Ambrosano GM, de Campos IT. Effects of a 10% Carbamide Peroxide Bleaching Agent on Roughness and Microhardness of Packable Composite Resins. J Esthet Restor Dent 2005;17:256-62.

32- Berastegui E, Canalda C, Brau E, Miquel C. Surface roughness of finished composite resins. J Prosthet Dent 1992; 68:742–9.

33- Wassell RW, McCabe JF, Walls AW. Wear characteristics in a two-body wear test. Dent Mater 1994; 10:269–74.

34- da Silva E M, Almeida G S, Poskus L T, Guimarães JG. Relationship between the degree of conversion, solubility and salivary sorption of a hybrid and a nanofilled resin composite: influence of the light-activation mode. J Appl Oral Sci 2008;16:161-6.

35- Sideridou I, Tserki V, Papanastasiou G. Study of water sorption, solubility and modulus of elasticity of light-cured dimethacrylate-based dental resins. Biomaterials. 2003 Feb;24(4):655-65.

36- Antonucci JM, Skrtic D. Effect of bifunctional comonomers on mechanical strength and water sorption of amorphous calcium phosphate- and silanized glass-filled Bis-GMA-based composites. Biomaterials 2003; 24: 2881–2888.

37- Santos C, Clarke RL, Braden M, Guitian F, Davy KWM. Water absorption characteristics of dental composites incorporating hydroxyapatite filler. Biomaterials 2002; 23: 1897-1904.

38- Ferracane JL, Berge XH, Condon JR. In vitro aging of dental composites in water effect of degree of conversion, filler volume, and filler/matrix coupling. J Biomed Mater Res 1998;42:465-72.

39- El-Murr J, Ruel D, St-Georges AJ. Effects of external bleaching on restorative materials: a review. J Can Dent Assoc. 2011; 77:b59.

40- Bueno RP R, Viaro PS, Nascimento PC, Pozzobon RT. Ion release from a composite resin after exposure to different 10% carbamide peroxide bleaching agents. J Appl Oral Sci 2012;20 (3) 335-9.