

Can the Static Magnetic Field Improve Orthodontic Adhesive Polymerization?

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Abstract

This study was designed to assess the effects of storage of light-cured orthodontic adhesives in Magnetic Field (MF) on its degree of conversion (DC %).

Heliosit and Biofix orthodontic adhesives were used in this study. They classified according to MF exposure into two groups (n=10 per group), with (MG) and without exposure (CG). MF was applied employing Neodymium Magnate magnets (set at 0.225 Tesla, and applied for 48 h continuously). The mesh surface of forty stainless steel metallic brackets was covered by a standardized quantity of orthodontic adhesives and polymerized for 20 sec on 70% reflectant background. Fourier transform infrared spectroscopy (FTIR/ATR) was used to appraise DC% before and after MF exposure. Wilcoxon signed rank test was used to test MF effects on the DC%. We found that the DC% of Biofix Orthodontic adhesive significantly increased from 40.29% (SD 3.51) to 52.76% (SD 3.13), while Heliosit reduced from 49.84 (SD 2.85) to 33.46% (SD 2.78). Also, the molecular conformations of these two composite adhesives were affected by the MF.

We concluded that the exposure to MF significantly increased the DC% of orthodontic adhesives composed of simple composite structures (Biofix), unlike complicated one (Heliosit) that was significantly diminished after MF exposure.

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Introduction

Since the commencement of using the composite adhesive for bracket bonding,^{1,2} the orthodontists reduce the utilization of orthodontic bands.^{3,4} As they (brackets) have an important impact on the accuracy and comfort of orthodontist work, in addition to the improvement in safety, comfort, and patients esthetics. The tooth - bracket adhesion in the fixed orthodontic therapy is considered as the successful key of the orthodontic treatment. The faller of this grip may complicate and increase the duration of malocclusion treatments. So, many attempts have been carried out to improve the stickiness of the composite orthodontic adhesive to the teeth, as well as improving their chemical stability

and physical properties.^{3,4,5} The property of any material results from their chemical matrix. The main component of the organic matrix of the composite orthodontic adhesive is monomers (metha-acrylic acid derivatives) with small molecules.⁶⁻⁸ During the polymerization, the composite orthodontic adhesive components joint to each other in chains and networks forming a polymer. The degrees of the polymerization characterize the chemical steadiness and physical properties of the formed polymer matrix, as well as its (polymer) mechanical properties and biological adverse response.^{9,10} The degree of conversion (DC) of the polymer template is the main representative of the percentage of polymerization, as it specifies the percentage of conversion of the double bond (C=C) of the monomer (Oligomer) molecules into macro-molecules with a particular intermolecular bond.^{10,11}

Since Faraday's days, the effects of magnate on the diamagnetic materials have been recognized. Recently, the trend is focusing on the magnetic effects on non-magnetic material (organic, inorganic, and polymers). This is

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particularly due to the development of superconducting technology and high magnetic field availability. Thus, nowadays it is possible to observe the magnetic effects on the polymer, wood, water, and living body.¹² The basis of the diamagnetism is origin from the induced motions of electrons when exposed to the magnetic field (MF).^{13,14}

In polymers, the anisotropy of the material after exposure to magnetism belongs to material chemical bonds. For example, the C-C bond, when the diamagnetic susceptibilities of these links are lesser and in parallel direction of the bond than that perpendicular to it, so the anisotropic diamagnetic surrender is negative and the bond is inclined to the direction at right angles to the magnetic force. While the aromatic rings usually align in the same of its ring plane and parallel to the applied MF, due to currents induced in the ring after exposure to the MF.^{12,15}

The alignment of the polymer structures under a high magnetic field has been reported in the literature. However, the mechanism of this transition is not reaching a unified view.^{16¹⁷}

The dental literature deliberated magnetic force in different dental treatment modalities, as it is used to support retention of dental prostheses¹⁷, maxillofacial prostheses,¹⁸ and also, in orthodontics to enhance tooth movements.^{17,20} In addition to its effect on teeth enamel and oral soft tissue.²²⁻²⁴ Up to date, no article discussed the effects of the magnetic field on the orthodontic adhesive polymerization process, in perfection or diminution mode.

This study aimed to evaluate the effects of exposure of orthodontic adhesives (Heliosit and Biofix orthodontic adhesives) to a high static magnetic field and to assess its consequence polymerization by calculating the degree of conversion.

Materials and methods

The protocol of this research was reviewed and approved by the research ethics committee (REC) at the College of Dentistry, University of Mosul (no. 4S/1060 in 25/ 6/ 2019). Two types of orthodontic adhesives were used in this study as shown in (Table 1). The two tested adhesives was classified according to the static magnetic field exposure (MF) into two groups (n=10 per group), with (MG) and without exposure (CG).

Orthodontic Adhesives Used in this Study	Chemical Composition	Lot
Heliosit Orthodontic (Ivoclar, Schaan, Liechtenstein)	Bisphenol A Glicidilmethacrylate 30-60%, Urethan dimethacrylate 10-30 %, Decandiol dimethaacylate 10-3-%, 2-(2-hydroxyl-5-methylphenyl)-benzotriazol; 2-(2H-Benzotriazol-2-yl)-p-kresol 0.1-1%, Silicon Dioxide, Catalysts, and Stabilizers.	G21064
Biofix (Biodinamica, Parana, Brazil)	Bisphenol A Glicidilmethacrylate 34.78%, Dimethacrylate urethane ethylene, Inorganic Filler 41.5%, Titanium Dioxide, Sodium Fluoride and Catalyst.	054 07

Table 1. Show the Chemical Structure of the Two Orthodontic Adhesives Used in this Study.

Exposure of uncured material in the MF

The MF was applied employing Neodymium Magnate (NdFeB) magnets (Quingado, Quingshing Magnets Company, Shandong, China). This type of magnet offers the highest magnetic energy per unit volume. The MF was set at 0.225 Tesla (T) as monitored by a Teslameter (GV-400T, Nihon Denji Sokki Co., Tachikawa, Tokyo, Japan). The magnetic field created from the magnets were arranged parallel to each other at the inner side of a main plastic tube. Another smaller plastic tube was inserted in the main tube to ensure stability (Figure 1. The terminal end of the inner tube was closed with a plastic stopper to prevent slipping of the adhesive tubes outside the field and ensure the magnetic exposure of the adhesive. The entire tube of each orthodontic adhesive was inserted at a right angle to the magnetic field and was stored for 48 h at room temperature to ensure complete magnetic saturation of the adhesive material).

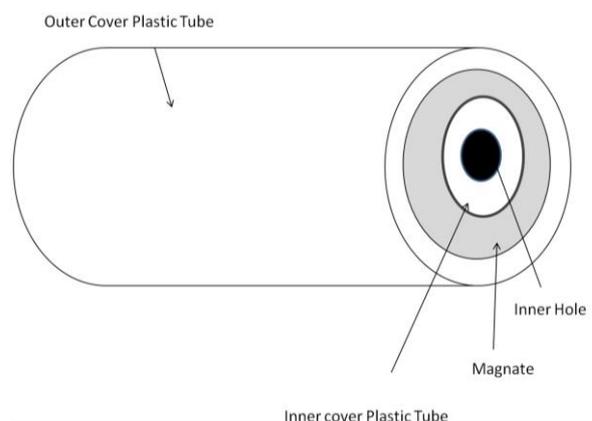


Figure 1. Schematic of the Magnetic Field Device.

Specimen Preparation

The mesh surface of standard edgewise stainless steel metallic brackets for the upper

central incisors (Ultratrim, Dentaurem, Ispringen, Germany) was covered by a standardized quantity of orthodontic adhesives and pressed against a smooth transparent cellulose film placed on a flat surface of 70 % reflectance to simulate enamel. A 20 g load was applied over each bracket to ensure a standardized film thickness, any adhesive excess was removed and then photo-polymerized for 20 s from cervical and incisal direction (10 s each) with 2 mm distance from the bracket, employing a LED curing unit (Valo, Ultradent Products Inc., South Jordan, UT, USA), operating in standard mode (1000 mW/cm² light intensity). For the MG group, the tubes after each use was reinserted in the MF to minimize magnetism loss. All the specimens were stored for 30 min at 37°C (dark/dry conditions) to include any post-curing effects.

The cellulose matrices was then removed and the central part of the exposed adhesive surface was pressed against a 45°-edge diamond crystal (1 mm diameter) of an attenuated total reflectance (ATR) accessory (Diamond crystal, Bruker Optics Ltd, Coventry, UK) attached to a Fourier transform infrared spectrometer (FTIR/Alpha II, Platinum, Bruker Optic GmbH, Ettlingen, Germany). Spectra of the polymerized specimens and of the uncured controls was acquired under the following conditions 4000-400 cm⁻¹ wavenumber range, 4 cm⁻¹ resolution, 20 spectra co addition, ~ 1 μm depth of analysis at 1000 cm⁻¹.

The spectra of the reference (uncured) and photo-polymerized specimens of each adhesive per treatment (MG, CG) was compared to identify possible changes in the relative peak intensities as a result of the magnetic field.

The degree of conversion (DC%) was calculated on a proportional percentage basis (two band method and the tangent baseline technique 252525 emploting the aliphatic C=C bond stretching vibrations at 1638 cm⁻¹ as an analytical band and the aromatic C..C bond stretching vibrations at 1608 cm⁻¹, which are not affected by the polymerization reaction, as a reference band. The DC% will be determined according to the following equation:

$$\% DC = 100 \times 1 - (AP (C=C) \times AM (C..C) / AM (C=C) \times AP (C..C))$$

where A (C=C), A(C..C) are the net peak absorbance areas of the polymerized (P) and un

polymerized (M) material at the specific bands respectively.

The results of DC% was checked for normal distribution using Shapiro-Wilk test. Comparisons was made using the type of adhesive material and storage condition (MG, CG) as independent parameters at a 95% confidence level (α=0.05) using Wilcoxon signed rank test.

Results

Figure 2 and figure 3 showed the full spectra of the FTIR/ATR chart for unset materials for Biofix and Heliosit respectively. The Heliosit chart of unset material showed a little increase in the absorbance between the spectra of 400 to 1200 cm⁻¹ (Finger print spectra). While the Biofix FTIR chart showed less change in figure print spectra between 400- 1200 cm⁻¹.

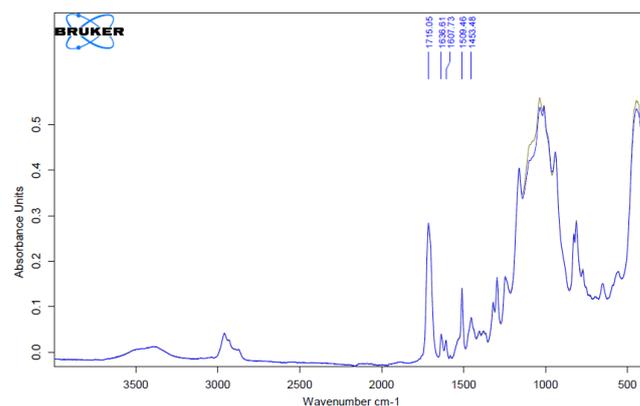


Figure 2. Schematic of the overlay of Full spectra of unset Biofix orthodontic adhesive for the magnetic (green line) and control group (blue line).

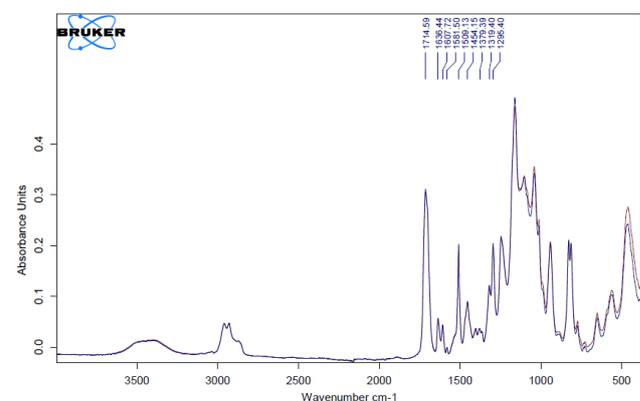


Figure 3. Schematic of the overlay of Full spectra of unset Heliosit orthodontic adhesive for the magnetic (red line) and control group (blue line).

The figure 4 and 5 showed the overlay full spectra for the control and magnetic absorption intensities for the Biofix and Heliosit respectively. The full spectra of the polymerized Heliosit adhesive showed decrease in the absorbance intensity for all the bands through the chart after exposure to MF. While the absorbance intensity of the Biofix was increase after exposure to the MG for all spectra.

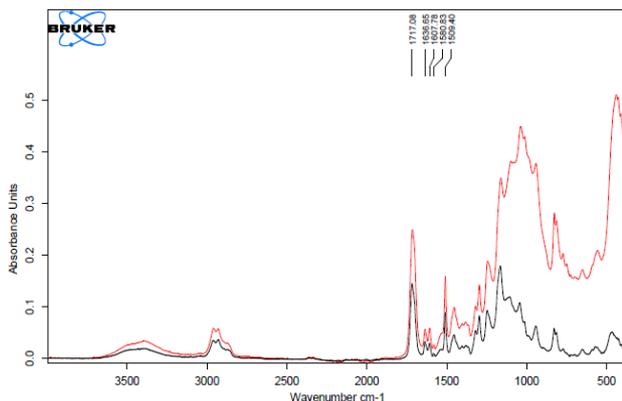


Figure 4. Schematic of the overlay of Full spectra of polymerized Biofix orthodontic adhesive for the magnetic (red line) and control group (blue line).

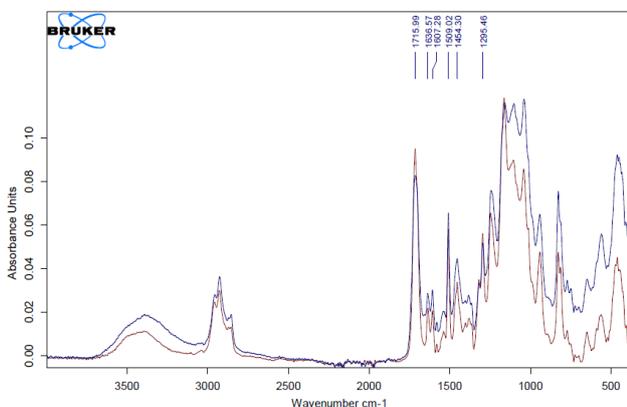


Figure 5. Schematic of the overlay of Full spectra of polymerized Heliosit orthodontic adhesive for the magnetic (red line) and control group (blue line).

The descriptive statistic (mean and stranded deviation) of the DC of both orthodontic adhesives under the two storage condition were listed in table 2. The DC of the CG Heliosit adhesive was 49.84 (SD 2.85), while for the MG was 33.45 (SD 2.78). Though the DC for the CG of Biofix adhesive was 40.29 (SD 3.51), while for the MG was 52.76 (SD 3.13).

The Wilcoxon signed rank Test showed a significant differences in the DC between the two adhesives (Biofix and Heliosit) under the two storage conditions (Z (2 tail) p value = -2.805 (0.005), -2.803(0.005)) respectively, as showed in table 2.

The DC of the Biofix orthodontic adhesive improved by 23.63%, while the DC of Heliosit orthodontic adhesive diminuend by 32.85% after Magnetic field exposure for 48 hours.

Adhesive	Mean DC*** (%)	SD**	Shapiro-Wilk test	Wilcoxon signed rank test* Z (2 tailed) (P) value
Biofix Control group	40.29	3.51	0.967	-2.805 (0.005)
Biofix Magnetic group	52.76	3.13	0.320	
Hileosit Control	49.84	2.85	0.874	-2.803(0.005)
Hileosit Magnetic group	33.46	2.78	0.596	

Table 2. Show the Means and Standard Deviation and Shapiro-Wilk test of the Degree of Conversion of the Tested Groups before and after Storage in Magnetic field and the Wilcoxon signed rank test results.

* $P < 0.05$, **Standard Deviation, *** Degree of Conversion.

Discussion

FTIR, among numerous methods, has been supported as a suitable analytic and powerful method.²⁶ It had been wildly used as a consistent technique. As it can detect the C=C extending vibrations directly before and after adhesive polymerization.

All the factors that could affect the DC, suggested by Eliades *et al.*^{27,28} were taken in consideration during carried out this research. The photo-polymerization and the FTIR/ATR analysis for all samples were carried out at the same time and room temperature and humidity. Even load was applied over the bracket to get a constant thickness of the sample, to simulate the normal condition. Samples were also cured with the same fully charged LED with constant distance, gingivally and buccally to the brackets base, with even mode for 10 sec each.

The 0.225 T magnetic field (MF) was prepared and evaluated by Tesla meter. This intensity are within the safe public exposure limits instructed by universal contract on Non Ionized Radiation Protection.^{21,29,30} The 48 hours exposure time to the MF was selected, as we expected that this period is enough to induce effect in the molecules of the unset orthodontic adhesive.

The DC was assessed by measuring the absorbance intensity at (1638 cm^{-1}) according to the previous authorized method. ^{25,31-33}

The DC of our control group for both adhesives used in this study was within the range of the DC of previous studies. Our DC of Biofix was 40.29 (SD 3.51) which is comparative to the DC calculated by Pithon *et al.*,³⁴ they get DC 44 (SD 2) after 24 hours of polymerization for 5*2 mm block sample polymerized directly (without bracket) for 40 sec. Their higher value could be related to LED intensity that were used which was 1400 mW/cm² and the absence of the bracket during polymerization. The DC of the control group of Heliosit adhesive are also within the range of previously published papers. Jagdish *et al.*,³⁵ get DC 48.63 (SD 0.34) which are closed to our DC = 49.84 (SD 2.85) as they used the same protocol for measuring the DC of the orthodontic adhesive under brackets.³⁶

The DC for the all samples were deliberate by the FTIR/ATR. The outcomes showed significant differences between the DC values of two orthodontic adhesives cured by LED after magnetic exposure.

From the FTIR chart, it's clear that the MF induce a deformation of the molecules that are clearly observe in finger print zone for both adhesives.

The response of the polymer to magnetic fields could be raised from their molecular dielectrical characteristics under magnetic force as space charge and electrical breakdown strength which have a significant effects on their mechanical properties and inter molecular interaction.^{37,38}

From our observations, we noticed that the MF can produce an effects on the chemical conformation of materials in different ways. As it stretching of the absorption unit of all the bands of the chemical structures of the Biofix adhesive this could be due to the variety in the dichroic ratio of the absorption bands induced by the change of the molecules arrangements from scattered to a regular form in the MF. Whereby, the high magnetic field will align the molecular in a manner that can improve the light absorption through the adhesive and thus improve the DC of the orthodontic composite for small molecular composing.^{38,39}

After MF exposure, the DC was significantly increased for Biofix orthodontic adhesive which composed of Dimethacrylate

urethane ethylene (without chain extender), and others that make it more flexible to oriented by the MF force and where the molecules can be aligned their structure within the field and thus improved the light absorption capacity of it and finally, rise their ability to react and ultimately increase the DC.³⁷⁻⁴⁰ As, the depth of the cure is depending on the light permeability of the filler, as well as monomer composition.^{31,33} While the Heliosit orthodontic adhesive has a more complicated structure as it contain (Decandiol dimethyaacrylate and others) which is less flexible structure that could induce incomplete orientation in the MF, as they stacked and fold back on itself and thus increase the light transmission and finally decrease the DC as it tied up the functional group action to the photo source.³⁹

The anisotropy of diamagnetism susceptibility of the composite materials are increased directly with the number of chains composed the molecules.^{39,40}

The process of Molecular re-arrangements under SMF are varies according to the complicity of the chemical structures and viscosity of the media.^{38,39} As they effects on the orientation of the intermolecular bond with the SMF which depends on the friction induce in a viscous solution.

Such new arrangements could be the responsible for changes in the rate of the recombination of the partials formed during the chemical reactions. More complex structures will induce more complex re arrangement that yield to un favorable DC results.³⁷⁻⁴⁰

Types and percentage of the filler in the composite also has a role on the yield DC as it regulated the conformational re-arrangements of the polymer with the SMF and control the filler matrix interface layer and improved its DC.³⁹

One of our surprising results of FTIR chart of the polymerized Biofix adhesive is that some bands; which are (439.91, 881.69, 1376.99, 1510.97, 2956.47) cm^{-1} ; were displaced slightly after exposure to MF in comparison to the control chart, this could be explained by that MF can affect the bonds of the molecule that induce shift of bands. Such shifting are clear with bands that induce Hydrogen which weakens the chemical bonds between the atoms and shift the band to lower frequency as affected by MF.³⁷⁻⁴⁰

For Heliosit adhesive such shifting is less clear than Biofix. This could be also, due to the

simple and shorter chains of the Biofix molecules that are highly oriented by the MF.

Limitation of this study

A small sample size per tested group, as well as only two tested material, could be the main limitation of this study, as it was showed by another researcher. However, all the factors that could affect FTIR analysis and DC calculation were the same except for the MF exposure. Another limitation related to the FTIR, as it highly affected by the concentrations of the materials that cannot be controlled absolutely. Also, we only exposed our adhesives to only one MF intensity (0.225T) for a specific exposure time.

Conclusions

Despite the limitations of this FTIR/ATR study, we can conclude the following:

- In the control group, the DC% of Heliosit is higher than Biofix orthodontic adhesives, under the same circumstances.
- The static MF has an effect on the DC of both tested orthodontic adhesives (Biofix, Heliosit).
- The molecular deformation could be induce due to bond angles alteration or bonds elongations induced by the MF.
- The Biofix DC% is significantly improved after MF exposure, while Heliosit adhesive DC% decrease under the same environments. The variety of the Composite response to MF is vary according to their degree of orientation order with MF. The complex chemical structure decrease their DC unlike simple one.
- Increase filler percentage of the composite highly increase DC under SMF.
- We speculated that the chemical conformation of these orthodontic adhesive affects after MF exposure.

Declaration of Interest

The authors report no conflict of interest.

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