Biodegradation Mechanisms of Restorative Dental Resin Composites

H.D.K. Yulianto
Department of Biomedical Science and Technology
Faculty of Dentistry, Universitas Gadjah Mada
Yogyakarta-Indonesia

Correspondence: H.D.K. Yulianto, c/o: Bagian Biomedik, Fakultas Kedokteran Gigi Universitas Gadjah Mada. Jl. Denta I, Sekip Utara Yogyakarta 55281, Indonesia. E-mail: dedykusuma@ugm.ac.id

ABSTRACT

Background: Sometime difficult question related with the survival time of dental resin composite restoration arises from our patient after their teeth has been restored with dental resin composites. Of course, precise time of the dental resin composite restoration maintained in their original shape cannot exactly be estimated. Although there are a number of different reasons as to why we cannot precisely estimate the survival time of dental resin composite restoration, the summarizing answer is brief: “The biodegradation process of dental resin composite is complex and includes several various factors.” Purpose: to review the relationship of mechanical, physical and mechanical factors in the role of the biodegradation of restorative dental resin composites. Literature review: Combinations of mechanical, chemical, and biological factors in oral environment have been identified as the important factors associated with decreasing surface properties and lost of their original shape. Initially during the biodegradation process of dental resin composite, small fraction of material component are detached from the surface, leaving various rough in the surface of the restoration. Surface roughness above the critical threshold value leads the adhesion of bacterial and biofilm formation on the dental resin composite surface. Once again, the question associated with the precise mechanism of bacterial adhesion and biofilm formations on the dental resin composite surface have not yet been identified. Since the knowledge currently available about the biodegradation mechanism of dental resin composite still limited, more research is needed in this field. Conclusion: Oral environmental changes within a restorative dental resin composites may affect the longevity of the composite restoration. The combination of mechanical and chemical factors is an important key to the role of the biodegradation material in oral environment.

Keywords: Dental resin composite; biodegradation; surface properties; oral environment

ABSTRAK

Latar belakang: Beberapa pasien sering menanyakan “berapa lama restorasi resin komposit tetap bertahan dan tidak terlepas?”. Pertanyaan ini tidak bisa dijawab secara akurat dalam satuan waktu karena proses biodegradasi restorasi resin komposit dalam rongga mulut sangat kompleks dan melibatkan interaksi dari banyak faktor. Tujuan: Studi pustaka ini bertujuan untuk mempelajari hubungan antara faktor mekanik, fisik, dan kimia terhadap proses biodegradasi tumpatan resin komposit di dalam rongga mulut. Tinjauan pustaka: Kombinasi antara faktor mekanik, fisik dan kimia di lingkungan rongga mulut telah diidentifikasi sebagai faktor penting yang terkait dengan perubahan struktur dan komposisi permukaan material restorasi resin komposit, sehingga secara klinis akan terlihat perubahan bentuk secara anatomi yang sedikit berbeda dari bentuk aslinya. Proses awal yang terjadi selama proses biodegradasi restorasi resin komposit gigi adalah terlepasnya sebagian kecil dari komponen material dari permukaan restorasi, sehingga meninggalkan kekerasan permukaan yang bervariasi tingkat kekasaranannya di seluruh permukaan restorasi. Keasaran permukaan mempunyai nilai ambang batas kritis yang mampu menyebabkan bakteri terakumulasi dan membelahkan biofilm. Adhesi bakteri dan pembentukan biofilm merupakan proses yang cukup rumit dan diprediksi mempunyai keterkaitan dengan proses biodegradasi restorasi resin komposit. Pertanyaan terkait dengan mekanisme yang tepat dari proses adhesi bakteri dan pembentukan biofilm pada permukaan restorasi resin komposit belum mendapat jawaban yang akurat, karena pengetahuan
INTRODUCTION

Dental caries is a major cause of tooth decay for most of Indonesian population. The main cause of dental caries is the attachment of bacteria that form biofilms on the surface layers of hard and soft tissues oral cavity. Currently, composite resin is still the main option for restoring dental hard tissue damage due to the process of caries. It is not only brought a change in materials and techniques but also a change in treatment philosophy called minimal invasive dentistry. Composites allow the possibility of preserving sound tooth structure during cavity preparation. Composites resins have the ability to bind to the dental hard tissues through the adhesive material. Furthermore, composite resin represents a significant aesthetic treatment option, enabling the fabrication of restorations with a natural appearance.

Table 1. Summary of the improvement of dental resin composite for which different material properties has been found

<table>
<thead>
<tr>
<th>Year</th>
<th>Material Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>glass filled PMMA</td>
</tr>
<tr>
<td>1960</td>
<td>PMMA → Bis GMA</td>
</tr>
<tr>
<td>1970</td>
<td>Filler: macrofill → microfill</td>
</tr>
<tr>
<td>1980</td>
<td>macrofill → hybrid; direct → indirect; hybrid → small particles</td>
</tr>
<tr>
<td>1990</td>
<td>flowables and packable</td>
</tr>
<tr>
<td>2000</td>
<td>microfill → nanofill</td>
</tr>
<tr>
<td>2010</td>
<td>self adhesive</td>
</tr>
<tr>
<td>2011</td>
<td>Nanofiller</td>
</tr>
<tr>
<td>2012-2014</td>
<td>nanofiller hybrid, nanocluster filler</td>
</tr>
</tbody>
</table>

Table 1 summarizes the improvement of physical and mechanical properties of dental resin composite. As can be seen, although marked improvements have been noted in terms of physical and mechanical properties during the last 10-20 years, several factors in dynamic oral environment can degrade the composite matrix via three principal modes, i.e.: mechanical degradation, physical degradation and chemical degradation. Dynamic changes of oral environment are influenced by food components, beverages, temperature changes, chewing, saliva and bacterial activity. Those factors have important role in the degradation of composite that clinically resulted various phenomena of failure, such as: discoloration, wear, ditching at the margins, delamination or simply fracture which may result in secondary dental caries.

**Initial biologic responses to resin composite surfaces**

The dental enamel and resin composite surface is a part that is always in contact with internal environment of oral cavity. Saliva, biofilm, and mastication force are identified as important contributing factors on dental resin composite biodegradation process. Resin composite surface is always encircled with saliva and form a thin layer of salivary pellicle, in which will promote adherence of oral bacteria. Adhesion of oral bacteria to salivary pellicle-coated tooth surface is critical step for oral bacteria colonization to form biofilm. Biofilm adsorption depends on biologic flow rate at the site of contact, the type of interfacial interaction involved, and attachment strength with the substrate. Adhesion and maturation of numerous species of cariogenic bacteria will promote maturation of biofilm. These biofilm will easily trapped on the groove of rough surface that is resulted from degradation process by salivary enzyme like cholinesterase (CE), thereby promoting maturation. The attachment of bacteria on the teeth/resin composite/other restorative materials depend on surface roughness and surface free energy. In vivo studies showed that in supragingival regions, roughness contribute more to plaque formation than does the surface free energy. The possible explanation are: (1) microbial binding strength is lower on low-energy surfaces. (2) High surface-free energy microorganism binds with high-energy surfaces and vice versa. (3) The surface free energy regulates the adhesive strength of pellicle against the shear detachment forces. (4) The increased surface area and decreased protruding height of well-spread cells may produce a geometric configuration with decreased flow resistance.
Prolonged biologic responses

Mastication forces during mastication process will result various degree of surface roughness on the dental resin composite surface. Surface roughness and porosity are important factors to be determined when the material is subject to the oral biological environment. At high flow rate, surface roughness and porosity produce local fluid motions of enhanced or reduced shear and will affect the shape, distribution, and aggregation of the attaching particles. At low flow rate or under static conditions, the grooves of rough surface may act as stagnation points, therefore promoting biofilm maturation.27

The role of surface roughness in biofilm formation has been widely investigated. Smooth polished surface of restoration have been shown to attract less biofilm in vivo compared to rough surface.24 Hydrophobic surface located supragingivally attract less biofilm in vivo than more hydrophilic surfaces over a 9-day period. Increasing both surface energy and surface roughness above a threshold value were found to result more biofilm accumulation on dental resin composite surfaces. The progression of a rough dental resin composite caused by mechanically wear process (adhesion, abrasion, fatigue, corrosion) has also been associated with biofilm formation.18

Bioadhesive activity of biofilm in biological environment depends on composition of outer monolayer and surface reactivity of outer monolayer. It can be explained that the material with high bioadhesive will increase surface tension and vice versa.28 High adhesion capability is one of the factors that determine the virulence of bacteria.29

Interaction between mastication force–saliva–biofilm is illustrated as chain “positive feedback loop”, which can be explained if there is one factor diminished, the chain will be broken.

Effect of surface properties on biofilm formation

Initial bacterial adhesion is the first step in the plaque formation and is facilitated by electrostatic interactions, hydrodynamic interactions, thermodynamic binding parameters, specific binding mechanism, and cementation by polysaccharide matrices or glucans. Extracellular polysaccharide or glucan is produced by bacteria and will provide barrier protection for trapped organic acid. Organic acid that is trapped within glucan barrier, resulting prolonged low pH around resin composite and tooth surfaces.29,30,31

The attached biofilm on resin composite and tooth surface can be classified as “retained biofilm” and “detached biofilm”. Biofilm attachment is predicted not only by single factor but might be come from several factors that will contribute together, like filler size, type of matrix monomer, surface roughness, and amount of unpolymerized monomers. The filler size and type of matrix monomer are depending on the type of resin composite material.31

The component of saliva that plays an important role in attachment of bacteria and biodegradation process are: albumin,29 salivary esterase, sucrose (glucan)-independent, aglutinins, proline-rich proteins, and mucins. Albumin plays a role in the adsorption and accumulation of bacteria on hard surfaces. Albumin is an inhibitor of hydrophobic interactions and will affect bacterial adhesion mediated by hydrophobic interactions.32-34 Cholesterol esterase (CE) and pseudocholinesterase (PCE) can hydrolyze bis-GMA and TEGDMA matrix synthetics monomer.35 Previous study showed that the amount and the pattern of protein adsorption onto the material surface is specific to the type of material.29 As the composition of composite may differ among brands, the salivary adsorption of composite may result different amount and pattern. Once in contact with resin composite surface, saliva is able to form adsorbed layers that are termed as conditioning film. Development of conditioning surface is considered as an initial stage in the process of biofilm formation.

DISCUSSION

Aging of composite resins in the oral cavity is very complex as depicted in Figure 1. Thermal changes, food, beverages, saliva, temperature will degrade composite restoration.

Numerous different in vitro models were developed to evaluate the effect of the oral environment on dental resin composite and each model proposed to simulate different factors. However, In vitro aging models for composites study only single factors thus lacking the synergy of factors operative in the oral cavity. Some studies has been widely demonstrated the bacterial attachment on the dental resin composite surfaces, however the molecular and physical interactions that govern bacterial adhesion to dental resin composite have not been understood in detail. Conditioning film is likely to change the physicochemical properties of resin composite and influence bacterial attachment.
Microorganisms in the oral environment not only form a biofilm on all available surfaces, including hard and soft tissue surfaces, but also on the surface of materials used for restoration of function or aesthetics. Exposure to saliva and biofilm lead to degradation of composite surfaces that may have increased roughness, sometimes accompanied by decreased microhardness and increased exposure of filler particles or matrix swelling. The amount of unpolymerized monomer released is caused by hydrolase activity cholin esterase-like of saliva. The leaching of unpolymerized monomer in specific amount is the marker that indicates the composite biodegradation process.

Previous study showed that exposure to biofilm is the best choice for in vitro aging of dental resin composite surfaces. To reflect what actually occurs in the oral environment, in situ studies that is used as a golden standard also has been done. However, both of exposure to biofilm and in situ study still has limitations. The biofilm study did not evaluate the role of each bacteria involved and the pattern of biofilm adsorption that may influence the aging of composite in these study. In the in situ study, the authors did not evaluate the effect of saliva protein and enzyme and the effect of teeth/restoration cleaning on the aging of composite. Based on the limitation of biofilm and in situ study, both of those studies is potential to be extended in the future research.

Several strategies have been done to reduce or avoid formation of biofilm on the dental resin composite surface by introducing antibacterial agents into dental composite. i.e.: silver and titanium, quaternary ammonium polyethyleneimine nanoparticles, alkylated ammonium chloride derivatives, chlorhexidine diacetate. Although several antibacterial agents are proved to have an antimicrobial effect, there are still problems introducing these antimicrobial agents into composites, such as the problem associated with reducing mechanical properties, polymer leakage, decrease of antimicrobial properties with time and reduced ability of the composite to light cure.

Considering the fact that biodegradation of dental resin composites as a result of aging challenges their integrity and longevity over time the properties of composite still need to be improved. The information derived from role of biodegradation dental resin composite under in situ and in vitro aging model and the effect of antibacterial agent will give scientific contribution on the development of antibacterial material to achieve clinically effective materials and to develop an agent that in the future can be minimized the attachment of bacterial on dental resin composite restoration.

REFERENCES