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Plant-derived bioactive compounds in contemporary restorative dentistry: Biological potential and clinical perspectives

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Abstract
Restorative Dentistry today is increasingly moving away from passive replacement of lost dental tissues and more toward biologically active methods that will preserve the remaining dentin structure, control the cariogenic biofilm, stabilize the dentin matrix and enhance restoration longevity. Of the interest in plant derived bioactive compounds, some phytochemicals have antimicrobial, antioxidant, anti-inflammatory, collagen-cross-linking, matrix metalloproteinase-inhibitory and remineralizing properties. Potential restorative molecules like proanthocyanidins, epigallocatechin-3-gallate, quercetin, resveratrol, curcumin, genipin, hesperidin and naturally occurring photosensitizing and cross-linking molecules have been tested for such use. Experimental studies suggest that these compounds can strengthen demineralized dentin, inhibit collagen degradation, decrease the activity of cariogenic biofilm, enhance the stability of resin-dentin interface, create a more favorable environment for mineral deposition [1-6]. Recently, the inclusion of phytochemicals in dental adhesives, and as polymerizable derivatives in composite materials, has provided an opportunity for the development of multifunctional restorative materials [7-11]. However, for the time being these are hampered by concentration-dependent effects, chemical instability, possible interference with resin polymerization, discoloration, and the absence of standardization of the formulations and limited clinical evidence over a long period. In this review, the biological basis, key phytochemical constituents, mechanism of action, therapeutic uses of phytochemicals in modern restorative dentistry are discussed, along with limitations and future prospects.

Keywords: Phytochemicals, restorative dentistry, dentin biomodification, dental adhesives, proanthocyanidins, EGCG, quercetin, resveratrol, curcumin, remineralization, bioactive dental materials

Introduction

Restorative dentistry's goals have grown significantly over the last few decades. Modern treatment does not just focus on the removal of diseased tooth structure and the replacement of an inert restorative material. The preservation of sound tissues, the control of recurrent disease-causing biological processes, and the reinforcement of weak dental structures and the development of materials that can interact therapeutically with the oral environment are increasing in importance.

The degradation at the resin-dentin interface is one of the critical drawbacks of adhesive restorations and has not been solved yet, although there have been significant advances in the development of resin composites and dental adhesive systems. Progressive failure of the hybrid layer due to hydrolytic degradation of adhesive polymers, incomplete resin infiltration and water sorption and deterioration of exposed dentinal collagen can compromise the hybrid layer [1]. Dentin can degrade in incompletely infiltrated regions by enzymes produced by the host, especially matrix metalloproteinases (MMPs) and cysteine cathepsins [1].

Conservation of collagenous dentin matrix has therefore been an important goal for achieving longevity of a restoration. Dentin biomodification is a technique to modify the biochemical and biomechanical properties of the dentin substrate prior to or during the restorative treatment [2]. Naturally occurring polyphenols and other molecules present in the plant life have been important in this respect in particular, as some of them are able to cross-link collagen, inhibit proteolytic enzymes, reduce microbial activity and influence mineral deposition [2,3].

Grape seed proanthocyanidins, epigallocatechin-3-gallate (EGCG) from green tea, quercetin from fruits and vegetables, resveratrol from grapes and berries, Curcuma longa extract, Gardenia species extract (genipin) and citrus fruits extract (hesperidin) are among the most widely studied naturally derived substances [3-6]. These molecules, which are not used as 'herbal remedies', are increasingly being explored as precisely formulated components of primers, adhesive systems and bioactive restorative biomaterials.

Principal Bioactive Compounds from Plants.

1. Proanthocyanidins

Condensed tannins are naturally occurring condensed tannins found in grape seeds, cocoa, berries and other plants. These are one of the best studied (not just researched) dentin biomodifiers derived from plants [2-5].

They are mainly important for their association with dentinal collagen. Proanthocyanidins may have a positive effect on the collagen cross-linking, mechanical properties of demineralized dentin and resistance to enzymatic degradation [3]. In an experimental model, Walter *et al*. demonstrated that the use of proanthocyanidins enhanced resistance of dentin collagen to collagenase degradation and slowed the progression of root-caries [5].

Hiraishi *et al*. found that proanthocyanidins, EGCG, hesperidin, and genipin are some of the agents found in

plants that contribute to better resistance of dentin collagen to enzymatic degradation after treated with selected phytochemicals [6].

Proanthocyanidins have thus been evaluated as dentin primers, preconditioners, adhesive additives and components of experimental biomodification procedures [2,3]. They are especially appealing for adhesive dentistry because they can impact both collagen and dentinal proteases.

However, challenges arise in the clinical translation due to variations in the phytochemical composition in botanical extracts. Proanthocyanidin activity is not just related to the concentration of proanthocyanidins, but also their molecular structure, degree of polymerization and botanical source [4].

2. Epigallocatechin-3-gallate

One of the most biologically active catechins in green tea (Camellia sinensis) is epigallocatechin-3gallate. EGCG has known antioxidant, anti-bacterial, collagen-preserving and protease-inhibitory properties applicable to restorative dentistry.

The current experimental application of EGCG to adhesives has been promising, with results varying by concentration. Incorporating EGCG in the dentin bonding process and altering the physicochemical properties of the experimental adhesives was possible, but the effect of the EGCG depended on the concentration and the dentin bonding strategy used, according to Macedo *et al.* [7].

Yu *et al*. showed that when the EGCG or its methylated derivative was included in an etch-and-rinse adhesive, it was able to provide antibacterial activity, inhibit dentin-derived proteases, and had improved bonding stability in experimental conditions [8].

EGCG has also been investigated as a dentin pretreatment. Under their experimental conditions, Yang *et al*. have reported that pretreatment with an EGCG-containing ethanol solution has been shown to result in improved bond stability of an etch-and-rinse adhesive [9].

One of the more recent developments is the chemical modification of EGCG to produce polymerizable derivatives. Duque *et al*. studied methacrylated EGCG molecules added to adhesive systems and concluded that the EGCG molecules effectively inhibited collagen degradation and gelatinolytic activity in the hybrid layer without interfering with bond strength under the conditions studied [15]. It may be possible to decrease the uncontrolled leaching of freely soluble phytochemicals and to incorporate therapeutic molecules into the polymer network by this means.

3. Quercetin

Quercetin is a flavonol naturally occurring in onions, apples, berries, tea and numerous other plants. This has caused it to be further studied in preventive and restorative dentistry due to its antioxidant, antimicrobial and enzyme-modulating properties.

Yang *et al*. formulated a quercetin doped dental adhesive and found that the optimized concentration of quercetin inhibited the growth of the S. mutans biofilm, decreased the activity of MMP, and reduced nanoleakage without compromising the bond strength and biocompatibility of the dental adhesive [10].

The use of quercetin in adhesives is not the only thing of interest. Recently, Nunes *et al*. conducted a scoping review of its effects on mineralized dental tissues and found potential benefits regarding bond strength, enamel and dentin properties, nanoleakage, erosion prevention and outcomes related to remineralization. [11] Most evidence available was, however, obtained from laboratory or in situ research, and the authors highlighted the need for clinical research [11].

Quercetin is thus a potentially versatile restorative ingredient to be developed, although the ideal formulation, concentration and clinical longterm performance of this ingredient is yet to be determined.

4. Resveratrol

Resveratrol is a naturally occurring stilbene polyphenol that is present in grape, berry, peanuts and similar botanical sources. It has antioxidant, anti-inflammatory, antimicrobial and antiproteolytic properties.

Peng *et al*. studied the aged bond strength, nanoleakage, MMP activity and S. mutans activity after resveratrol/ethanol pretreatment of dentin, and determined that an optimized concentration of resveratrol resulted in an increased aged bond strength, decreased nanoleakage, inhibited MMP activity and suppressed S. mutans activity *in vitro* [12].

The compound has also used directly in adhesive formulation. Guo *et al*. found that a resveratrol-doped adhesive performed well in terms of bonding properties after artificial aging while decreasing the amount of nanoleakage and endogenous protease activity and S. mutans biofilm formation [13].

The results indicate that there are two possible strategies for resveratrol: as an independent dentin biomodifying priming agent or as inclusion in the adhesive system.

5. Curcumin

Curcumin is a polyphenolic compound that is mainly obtained from the rhizomes of Curcuma longa. It is an antioxidant, anti-inflammatory, anti-microbial and a natural photosensitizer.

In particular, curcumin holds promise in antimicrobial photodynamic therapy. Curcumin, upon activation under the right light conditions, can help to produce reactive oxygen species that can damage microbial cells. A systematic review and network meta-analysis by Ferrisse *et al*. showed that antimicrobial photodynamic therapy using curcumin resulted in a decrease in oral microbial load, but they believed more randomized clinical trials were needed to confirm this effect [16].

In the context of restorative dentistry, this antimicrobial property could have implications for cavity disinfection and biofilm control. The evidence supporting the routine use of curcumin in permanent restorative materials is less developed than evidence for proanthocyanidins, EGCG, quercetin or resveratrol.

Further, curcumin is poorly soluble in water, and chemically unstable. Some controlled delivery systems, such as nanoparticles, micelles and hydrogels, may help make it more clinically applicable one day.

6. Genipin

Genipin is a naturally occurring cross-linking molecule from Gardenia species. It has been tested as a biological collagen modifier and as an alternative to the conventional synthetic cross-linkers.

The biochemical changes of dentin collagen induced by genipin treatment were found to be measurable, and genipin was shown to have an impact on the stability of collagen [17]. Previous research had also demonstrated that genipin was more resistant to degradation of collagen than other cross-linking agents [5].
Although it is biologically potential, it needs to be considered prior to adding it to their routine restorative practices, as some of the factors involved are treatment duration, discoloration and concentration dependent effects.

7. Hesperidin

Hesperidin is a flavanone glycoside, primarily occurring in citrus fruits. It has antioxidant properties and has shown to have dentin collagen preservation activity.
Islam *et al*. studied hesperidin in demineralised root dentin and showed its influence on collagen degradation and the demineralisation/remineralisation properties [18]. Hesperidin also has been reported to enhance dentinal collagen resistance to enzyme degradation [6] as reported by Hiraishi *et al*.
The results indicate possible future dentin preservation and minimally invasive treatment of caries possibilities, but restorative uses are still experimental.

Biochemistry of compounds from plants for restorative dentistry.

1. Dentin collagen stabilization

The major organic matrix of dentin is composed of type I collagen. In acid-etching processes, the hydroxyapatite is removed, leaving a 3D collagen network which must be expanded and properly infiltrated with adhesive monomers. Areas of exposed collagen that are not completely infiltrated become vulnerable to hydrolysis and enzymatic degradation [1,2].
Collagen's ability to interact with plant polyphenols by hydrogen bonding, hydrophobic interactions and other molecular interactions. Some compounds (particularly proanthocyanidins) can enhance the mechanical properties of demineralized dentin and its resistance to enzymatic breakdown [3-6].
Aguiar *et al*. proved that the source of plant polyphenol extracts and their chemical composition can affect dentin biomodification [4]. Treating dentins with extracts from Vitis vinifera, Theobroma cacao, Camellia sinensis and Pinus massoniana resulted in measurable changes in dentin properties, but to different extents depending on the polyphenolic composition of the extracts [4].

2. Inhibition of proteolytic enzymes.

One of the mechanisms related to the degradation of the resin-dentin interface is MMP mediated degradation [1]. Therefore, the inhibition of dentinal endogenous proteases is an interesting approach in the quest to improve the durability of bonded restorations.
There are several compounds found in plants that have antiproteolytic activity. The importance of proanthocyanidins is that they can act as collagen cross-linkers and as dentinal proteases inhibitors [3]. There are also some experimental models that show that EGCG, hesperidin, quercetin and resveratrol inhibit collagenolytic or gelatinolytic activity [6-13].

3. Antibacterial and antibiofilm activity

Secondary caries is one of the most common biological problems that can occur after restorative treatment. Cariogenic microorganisms such as Streptococcus mutans are capable of colonizing margins of the restoration and play a role in acid production, EPS production and progressive mineral loss.
A number of polyphenols derived from plants can disrupt bacterial growth processes, biofilm maturation and virulence related processes. EGCG-altered adhesives have been shown to inhibit S. mutans biofilm formation, as well as having activities against collagen-degrading enzymes [8]. Quercetin and resveratrol-containing adhesives also have been demonstrated to be antibacterial or antibiofilm *in vitro* studies [10-13].
The multifunctional nature of this activity makes it clinically appealing because an adhesive product that could have multiple functions to preserve the hybrid layer as well as prevent the growth of cariogenic biofilm could possibly solve two main reasons that lead to failure of restorations.

4. Minerals, remineralization, and preservation of mineralized tissues

A new paradigm in minimally invasive dentistry is to preserve remineralizable dental tissue instead of copiously removing affected dentin. Collagen is important as it is a structural matrix in which mineral deposition can happen; therefore, stabilization of the collagen scaffold is particularly crucial.
The polyphenolic compounds present in a plant can indirectly participate in remineralization by preserving the collagen, inhibiting the degradation by proteases and stabilizing the organic structure. According to the recent reviews, flavonoids and polyphenols within the group of natural bioactive substances have potential but can be used in clinical practice only in a standardised way, which has not yet been fully realised [14].

Summary of Important Phytochemicals

Table 1: Summary of major phytochemicals and proposed restorative applications

Compound	Principal source	Major proposed biological effects	Potential restorative application
Proanthocyanidins	Grape seed, cocoa, berries	Collagen cross-linking, MMP inhibition, resistance to biodegradation	Dentin primer, biomodification, adhesiveinterface stabilization
EGCG	Green tea	Antiproteolytic, antimicrobial, antioxidant, collagen protection	Adhesive additive, dentin pretreatment, therapeutic adhesives
Quercetin	Apples, onions, berries, tea	Antibacterial, MMP inhibition, antioxidant, reduced nanoleakage	Multifunctional adhesive, dentin/enamel protection
Resveratrol	Grapes, berries, peanuts	Antibiofilm, antiproteolytic, antioxidant	Dentin primer and adhesive additive

Curcumin	Turmeric	Antimicrobial, antioxidant, anti-inflammatory, photosensitizing	Photodynamic disinfection and experimental restorative systems
Genipin	Gardenia species	Natural collagen cross-linking	Dentin matrix stabilization
Hesperidin	Citrus fruits	Collagen preservation, antioxidant action	Dentin biomodification and caries-related applications

Incorporation into Restorative Materials

There are several ways in which bioactive compounds derived from plants can be used to aid in restorative treatment.

Dentin pretreatment is the easiest method, and involves applying a phytochemical solution to the surface of the tooth before the application of the adhesive. This approach has been taken to study proanthocyanidins, EGCG and resveratrol [3,9,12]. Exposed dentin allows direct interaction with the phytochemical and collagen matrix, and a second clinical step and application time is required.

A second approach is to embed the bioactive molecule in a dental adhesive. EGCG, quercetin and resveratrol have been assessed using this method [7,8,10,13]. This is clinically desirable, since the therapeutic activity could, in theory, be added without the need for an additional operative step.

But the introduction of phytochemicals into resin systems is not easy. Several polyphenols are powerful antioxidants and radical scavengers. They could affect the degree of conversion or the mechanical properties of the polymer when used at unsuitable concentrations, as they can inhibit free radical polymerisation. Macedo *et al*., for instance, showed that the physicochemical properties changed depending on the concentration of EGCG and its adhesive properties [7].

More advanced is the creation of polymerizable derivatives of phytochemicals. For instance, methacrylated EGCG is a natural molecule that has been chemically modified to work better with methacrylate based restorative systems [15]. These strategies could allow for biological activity without uncontrolled release from the polymer network.

Nanotechnology and controlled-release systems are other possibilities. Encapsulation can help to stabilize and enhance the solubility of compounds like curcumin, allowing for a more gradual release and thus prolonged therapeutic effects. However, release behavior, cytotoxicity, mechanical properties and long-term material stability should be assessed prior to clinical use.

Clinical relevance and present shortcomings

The scientific potential of plant derived bioactive compounds is the multifunctionality of these compounds. One molecule can effectively act as a collagen stabilizer, inhibit proteases and have antimicrobial activity, thereby tackling multiple mechanisms that cause restoration failure at a single time.

The clinical safety and effectiveness of products of natural origin, however, cannot be assumed. Biological response is related to concentration, purity, molecular composition, extraction procedure and length of exposure.

The standardization of plant extracts is one of the major issues. The amounts and structure of polyphenols in various plant sources can vary significantly, and this may affect dentin biomodification [4].

Another area of concern is material compatibility. Antioxidants containing too much occur in the polymerisation and change the mechanical property [7]. Other phytochemicals are also strongly coloured which can pose esthetic concerns with the use of tooth coloured restorative materials.

Additional challenges are stability and controlled release. The antimicrobial activity of an adhesive may be temporarily achieved from a rapid release, and may lead to water sorption or loss of structural integrity. On the other hand, strong immobilisation of the active compound within the polymer may reduce its biological availability.

The majority of the current evidence comes from *in vitro* studies of teeth that have been extracted, single-species biofilms, collagenase aging, water storage and thermocycling. Recent reviews of quercetin and natural biomineralization agents reiterate that there is more laboratory evidence than clinical evidence [11,14].

Based on the currently available evidence, therefore, bioactive compounds derived from plants are likely to be promising experimental biomaterial components, but not proven alternatives to the conventional restorative protocols.

Future Perspectives

Further studies should shift from a crude plant extract to well defined and chemically characterized molecules. The ability to identify precisely the structures involved in collagen interaction, MMP inhibition and antimicrobial activity could allow for the reproducible formulation and dosage.

Development of polymerizable bioactive molecules is particularly promising. The fact that methacrylated EGCG is the subject of an investigation, which is a naturally occurring chemical compound that can be chemically modified to be used in resin-based restorative systems, is an indicator of how a naturally derived compound can be used in chemically modified ways [15].

Combination strategies should also be considered. A possible restorative material could include a collagen stabilizing phytochemical and remineralising calcium phosphate or bioactive-glass fillers. This formulation might have the potential to safeguard the organic dentin matrix while at the same time delivering mineral ions needed for remineralization.

Nanocarriers can be used to achieve sustained delivery of phytochemicals or delivery on demand. Ideally, antimicrobials may be released in the presence of acidic conditions and/or high bacterial numbers, not on a continuous basis, thus maintaining the therapeutic reservoir.

It would be beneficial for future studies to focus on clinically relevant application time and concentration, multispecies oral biofilms, pulpal cytotoxicity, color stability, degree of conversion, mechanical properties and long-term aging.

Most importantly, clinical trials with randomisation are necessary. Outcomes should not only encompass bond strength in the lab, but also restoration survival, marginal adaptation, secondary caries, postoperative sensitivity, discoloration and patient-centered clinical outcomes.

Conclusion

It is noteworthy that products derived from plants with bioactivities are emerging areas in modern restorative dentistry. They are not just natural, but also have biological

response to dentin, microorganisms, and restorative interfaces.

Proanthocyanidins also show potent dentin collagen cross-linking and matrix degradation inhibitory properties [3-5]. EGCG has been shown to have antiproteolytic and antimicrobial properties and can be added to adhesive systems [7-9,15]. Quercetin has worked well on bonding, MMP activity, bacterial biofilm and mineralized dental tissues [10,11] and resveratrol can positively impact on the bond durability and antibiofilm properties [12,13]. Other antimicrobial/anti-collagen effects are possible with curcumin, genipin and hesperidin [16-18].

However, efficacy in the laboratory doesn't always mean effectiveness in the clinic. Optimized formulations, development of standardized concentrations, satisfactory optical and mechanical characteristics and extended clinical studies still need to be conducted.

The most likely future direction of the phytochemicals, however, is not for them to take the place of traditional restorative materials with herbal formulations. Instead, well-defined molecules derived from plants could serve as functional parts of scientifically designed primers, adhesives and repair materials. The ability of these multifunctional biomaterials to be able to protect and interact with the dentin could contribute to the transition from passive replacement of dental tissues to dental restoration that can protect and interact with the remaining tooth structure.

References

1. Frassetto A, Breschi L, Turco G, Marchesi G, Di Lenarda R, Tay FR, *et al*. Mechanisms of degradation of the hybrid layer in adhesive dentistry and therapeutic agents to improve bond durability: a literature review. Dent Mater. 2016;32(2):e41-e53. doi: 10.1016/j.dental.2015.11.007.
2. Bedran-Russo AK, Pauli GF, Chen SN, McAlpine J, Castellan CS, Phansalkar RS, *et al*. Dentin biomodification: strategies, renewable resources and clinical applications. Dent Mater. 2014;30(1):62- doi: 10.1016/j.dental.2013.10.012.
3. Balalaie A, Rezvani MB, Mohammadi Basir M. Dual function of proanthocyanidins as both MMP inhibitor and crosslinker in dentin biomodification: a literature review. Dent Mater J. 2018;37(2):173182. doi:10.4012/dmj.2017-062.
4. Aguiar TR, Vidal CMP, Phansalkar RS, Todorova I, Napolitano JG, McAlpine JB, *et al*. Dentin biomodification potential depends on polyphenol source. J Dent Res. 2014;93(4):417-422. doi:10.1177/0022034514523783.
5. Walter R, Miguez PA, Arnold RR, Pereira PNR, Duarte WR, Yamauchi M. Effects of natural crosslinkers on the stability of dentin collagen and the inhibition of root caries *in vitro*. Caries Res. 2008;42(4):263-268. doi:10.1159/000135671.
6. Hiraishi N, Sono R, Islam MS, Yiu C, Nakamura H, Otsuki M, *et al*. *In vitro* evaluation of plantderived agents to preserve dentin collagen. Dent Mater. 2013;29(10):1048-1054. doi: 10.1016/j.dental.2013.07.015.
7. de Macedo FAA, Souza NO, Lemos MVS, De-Paula DM, Santiago SL, Feitosa VP. Dentin bonding and physicochemical properties of adhesives incorporated with epigallocatechin-3-gallate. Odontology. 2019;107(1):23-28. doi:10.1007/s10266-018-0367-0.
8. Yu HH, Zhang L, Yu F, Li F, Liu ZY, Chen JH. Epigallocatechin-3-gallate and epigallocatechin-3O-(3-O-methyl)-gallate enhance the bonding stability of an etch-and-rinse adhesive to dentin. Materials (Basel). 2017;10(2):183. doi:10.3390/ma10020183.
9. Yang H, Guo J, Deng D, Chen Z, Huang C. Effect of adjunctive application of epigallocatechin-3gallate and ethanol-wet bonding on adhesive-dentin bonds. J Dent. 2016; 44:44-49. doi: 10.1016/j.jdent.2015.12.001.
10. Yang H, Li K, Yan H, Liu S, Wang Y, Huang C. High-performance therapeutic quercetin-doped adhesive for adhesive-dentin interfaces. Sci Rep. 2017; 7:8189. doi:10.1038/s41598-017-08633-3.
11. Nunes GP, de Oliveira Alves R, Ragghianti MHF, Dos Reis-Prado AH, de Toledo PTA, Martins TP, *et al*. Effects of quercetin on mineralized dental tissues: a scoping review. Arch Oral Biol. 2025; 169:106119. doi: 10.1016/j.archoralbio.2024.106119.
12. Peng W, Yi L, Wang Z, Yang H, Huang C. Effects of resveratrol/ethanol pretreatment on dentin bonding durability. Mater Sci Eng C Mater Biol Appl. 2020; 114:111000. doi: 10.1016/j.msec.2020.111000.
13. Guo R, Peng W, Yang H, Yao C, Yu J, Huang C. Evaluation of resveratrol-doped adhesive with advanced dentin bond durability. J Dent. 2021; 114:103817. doi: 10.1016/j.jdent.2021.103817.
14. Liu Y, Wu Z. Biomineralization of dental tissues with natural drugs: a comprehensive review. Saudi Dent J. 2025;37(4-6). doi:10.1007/s44445-025-00036-9.
15. Duque C, Chrisostomo DA, Scaffa PMC, Gouveia Z, Nascimento FD, Plotnikov SV, Prakki A. Methacrylated epigallocatechin gallate functionalized dental adhesives: antiproteolytic activity and dentin bonding studies. Dent Mater. 2025;41(7):892-900. doi: 10.1016/j.dental.2025.05.006.
16. Ferrisse TM, Dias LM, de Oliveira AB, Jordão CC, Mima EGO, Pavarina AC. Efficacy of curcumin-mediated antibacterial photodynamic therapy for oral antisepsis: a systematic review and network meta-analysis of randomized clinical trials. Photodiagnosis Photodyn Ther. 2022; 39:102876. doi: 10.1016/j.pdpdt.2022.102876.
17. Nagaoka H, Nagaoka H, Walter R, Boushell LW, Miguez PA, Burton A, *et al*. Characterization of genipin-modified dentin collagen. Biomed Res Int. 2014; 2014:702821. doi:10.1155/2014/702821.
18. Islam SM, Hiraishi N, Nassar M, Sono R, Otsuki M, Takatsuka T, *et al*. *In vitro* effect of hesperidin on root dentin collagen and de/re-mineralization. Dent Mater J. 2012;31(3):362-367. doi:10.4012/dmj.2011-203.