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REVIEW

Surface Modification of Glass Fiber-Reinforced Composite Posts by Hydrogen Peroxide: A Scoping Review

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Abstract

On the rehabilitation of endodontic treated teeth using intraradicular retention, adhesive failures often occur between the intraradicular post and the resin-matrix cement. The main aim of this study was to conduct a scoping review on the surface modification of glass fiber-reinforced composite posts by hydrogen peroxide solutions. An electronic search was performed in the PubMed database, using combinations of keywords pursuing articles published between 2010 and 2024 in English language. Of the 13 selected studies, 12 investigated the bond strength between the glass fiber-reinforced composite (GFRC) post and the resin-matrix cement after the surface treatment of the post, 5 articles analyzed failures using a stereomicroscope, and 7 studies analyzed the surface topography by scanning electron microscopy (SEM). Etching procedures with hydrogen peroxide (H_2O_2) altered the surface of the GFRC post by selectively dissolving the matrix without damaging the fibers, resulting in a larger surface area of exposed fibers available to react with the adhesive system or silane. Studies revealed high bond strength values between the etched GFRC posts to the resin-matrix materials. Surface treatment of GFRC posts with hydrogen peroxide seems promising considering the feasibility on the surface modification resulting in the improvement of bond strength of intraradicular posts to resin-matrix cements.

Keywords Hydrogen peroxide · Endodontic post · Intraradicular post · Fiber-reinforced post · Surface

Introduction

The long-term performance of endodontic treated teeth depends on a high-quality coronal restoration and the apical sealing [1]. Endodontically treated teeth with lack of coronal tooth structure are exposed to shearing chewing forces and commonly need the placement of a intraradicular post to ensure adequate sealing and retention of the restorative materials [2, 3]. Cast metal posts and cores have been traditionally used to provide the desirable retention for the tooth restoration. The main disadvantage of cast metal posts is the mismatch in mechanical properties when compared to the tooth structures. Previous studies have reported the use of a post with a Young modulus higher than the dentin can result in stresses at interfaces and can cause the detachment of the intraradicular post or a even the tooth root fracture [4]. In the last decade, the use of glass fiber-reinforced composte (GFRC) posts in the restoration of endodontically treated teeth has increased in popularity because of their aesthetics and mechanical properties. GFRC posts were rapidly accepted by clinicians as promising alternatives to cast metal

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posts, as their elastic moduli are similar to dentin, producing a favorable stress distribution, reducing the risk of root's catastrophic fractures [3, 5, 6]. Moreover, GFRC posts provide proper aesthetic outcomes for endodontically treated anterior teeth, easier removal, and less treatment visits [3, 7].

The clinical success of a post-and-core restoration for endodontically treated teeth depends on the materials, design, and the quality of the post-and-core interface [2]. The establishments of reliable bonds at the root-post-core interfaces are important for transfering stress under functional loading [7]. In vitro and in vivo research indicates that failures of GFRC post-and-core restorations often occur because of debonding between the GFRC-to-resin cement and/or between the resin-matrix cement-to-root canal dentin interfaces [3]. The lack of adhesion between the GFRC posts and the restorative composites result from the absence of chemical bonds between the epoxy matrix of the posts and the methacrylate-based resin composites based.

In an attempt to maximize resin bonding to GFRC posts, several surface modification approaches have been recently suggested [6] focusing on the chemical and micromechanical retention between different materials [8]. The application of a silane coupling agent such as 3-methacryloxypropyltrimethoxysilane is used as adhesion promoter over GFRC post-to-core units. Silane agents provide enhanced surface wettability with chemical bridge formation between the methacrylate matrix of the adhesive resin-matrix or composite core and the glassy phase of the GFRC post [2]. However, solely silane agents cannot establish a strong bond between GFRC posts and resin-matrix composite cements and therefore a combination of methods involving micro-scale surface modification and subsequent silane application, is commonly used in clinical practice [9, 10]. Nevertheless, gritblasting used to increase roughness of GFRC, can damage the fibers and affect the GFRC post integrity [10]. Other chemical treatments have been proposed such as hydrogen peroxide, potassium permanganate, and sodium ethoxide. Hydrogen peroxide is commonly used in dental practice, mostly for dental bleaching [2] . Recent studies have proposed that hydrogen peroxide shows an etching effect over GFRC posts by breaking epoxy matrix bond through a mechanism of substrate oxidation [9].

The main aim of this study was to conduct a scoping review on the surface modification of GFRC composite posts by hydrogen peroxide solutions. It was hypothesized that hydrogen peroxide chemically react with the organic matrix surfaces of GFRC composite posts resulting in increased roughness leading to an enhanced bond strength to resin-matrix cements.

Method

Information Sources and Search Strategy

A literature search was performed on PubMed (via National Library of Medicine) considering such database includes the major articles in the field of dentistry and biomaterials. The present search of studies was carried out in accordance with previous integrative and scoping review studies [11–13]. The following combination of search terms were applied in this study: "hydrogen peroxide" AND "surface" AND "endodontic post" OR "intracanal post" OR "intraradicular post" OR "fiber reinforced" OR "fiber post". The inclusion criteria involved articles published in the English language from 2010 up to 2024, reporting the effects of the hydrogen peroxide conditioning on the surface modification of tooth intracanal posts and on the bond strength between the post and resin-matrix cement. The eligibility inclusion criteria used for article searches also involved: in vitro studies; meta-analyses; randomized controlled trials; prospective cohort studies and studies based on glass, quartz or carbon fibers endodontics posts. The exclusion criteria were the following: articles without abstracts, systematic reviews, bibliography review, theses and dissertations; articles whose titles and/or abstracts do not fit the theme; all articles in a foreign language (not in the English language), in which the full texts were not available; studies testing endodontic posts other than fiber-reinforced composites (i.e., metal posts and studies with no control group). Also, a hand search was performed on the reference lists of all primary sources and eligible studies of this scoping review for additional relevant publications. Studies based on publication date were not restricted during the search process. A research question has been formulated following the PICO (Population, Intervention, Comparison, and Outcome) approach as follow: "Can hydrogen peroxide chemically react with the organic matrix surfaces of GFRC composite posts resulting in increased roughness? The following factors were taken into consideration: (i) Population: GFRC composite posts, hydrogen peroxide solutions, human participants, animals, teeth; (ii) Intervention: mechanical assays, surface analyses, optical analyses, microscopy, chemical analyses, adhesive procedures, and equipment; (iii) Comparison: different GFRC composite posts, types of hydrogen peroxide, other chemical substances, adhesion parameters, types of resin-matrix cements. (iv) Outcomes: major findings related to the surface modification of GFRC composite posts.

Study Selection and Data Collection Process

The articles retrieved by the search process were evaluated in three steps. Studies were primarily scanned for relevance by title, and the abstracts of those that were not excluded at this stage were assessed. Three of the authors (JCMS, VF, CT) independently analyzed the titles and abstracts of the retrieved, potentially relevant articles meeting the inclusion criteria. The total of articles was compiled for each combination of key terms and therefore the duplicates were removed using Mendeley citation manager (Ed. Elsevier). The second step comprised the evaluation of the abstracts and non-excluded articles, according to the eligibility criteria on the abstract review. A preliminary evaluation of the abstracts was carried out to establish whether the articles met the purpose of the study. At last, the eligible articles received a study nomenclature label, combining first author names and year of publication. The following variables were collected for this review: authors' names, publication year, aims, type of study, study design, post type, composite core material, type of analysis, and main outcomes. Data of the studies were harvested directly into a specific data-collection form to preventing multiple data recording within the same study (e.g., reports with different set-ups). Such evaluation was individually carried out by two researchers, followed by a joint discussion to select the most relevant studies.

Results

The literature search identified a total of 147 articles in PubMed, as shown in Fig. 1. Duplicates were removed, and then titles and abstracts of 83 articles were independently evaluated by three authors. A total of 67 articles was excluded because they did not meet the inclusion criteria. The remaining 16 potentially relevant studies were then evaluated. Of those studies, 3 were excluded because they did not provide comprehensive data considering the purpose of this study. At last, 13 studies were included in this review.

Regarding the publication period, four articles on the subject was recorded in 2013 (30.7%) while two studies were published in each 2011, 2012, 2014 , and 2017 (61.5%) and, one study was published in 2016. All the selected studies were performed in vitro. Of the 13 selected studies, 12

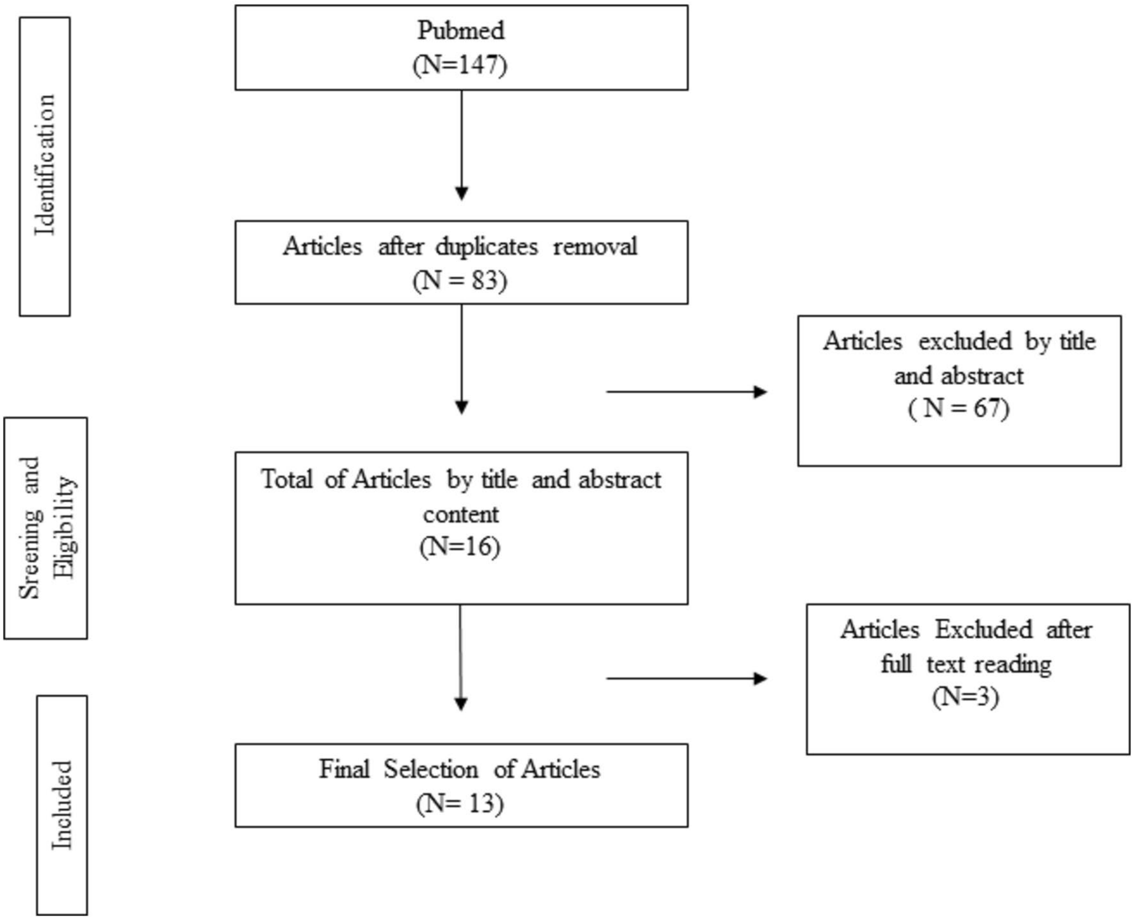

Fig. 1 Prisma flow diagram of the search strategy

investigated the interfacial strength between GFRC post and composite after different surface treatment using different tests with universal testing machine (Fig. 2A). Five studies analyzed types of failures using a stereomicroscope while 7 studies analyzed surface topographical using SEM. The retrieved data on the resin-matrix cement, intracanal post, and surface modification are given in Table 1. Most relevant results found in each study were subsequently extracted and organized in a table in order to provide a more dynamic, interactive, and structured analysis. In the included studies, hydrogen peroxide was used for the pretreatment of GFRC posts at concentrations varying from 6 up to 50% for immersion time from 5 up to 20 min; although concentration at 10% and 24% were the most cited. The concentrations and times of applications used were identified in Fig. 2B.

The major findings are drawn as follow:

- The use of silanes to enhance bond strength between resin-matrix composite and the GFRC post remains controversial [14]. Two studies reported an increasing significantly effect of silanization on the bond strength between the post and resin-matrix cement compared to untreated controls, while other studies did not detect any significantly differences between silanated and untreated GFRC posts [2, 10, 15].
- SEM examinations showed that application of surface pretreatment affected the surface morphologic aspects of GFRC posts. Non-etched GFRC post showed a relatively smooth surface without fiber exposure. Hydrogen peroxide may effectively induce a dissolution of the resin matrix, exposing the fiber content to the silane conditioning [2, 6, 14, 16–18]. The exposed fibers were not damaged or fractured by H_2O_2 unlike treatment of GFRC post with silica coating with 30-mm SiOx and air abrasion with 50-mm Al_2O_3 particles [18].
- Seven studies concluded that the pretreatment of GFRC posts using H_2O_2 followed by silanization resulted in increased bond strength to resin-matrix materials [10, 16–19]. Microscopy showed predominant adhesive fracture pattern failure between GFRC posts and resin-matrix material [2, 10, 18, 19].
- The concentration and exposure time of H_2O_2 as influencing factors in increasing the bonding strength are controversial [2, 17]. The use of 10% H_2O_2 for 5 or 10 min did not have a significant effect on the GFRC post/core bond strength unlike 30% H_2O_2 for 5 or 10 min as compared with the control and silanization groups. However, a previous study reported that 24% H_2O_2 applied to the GFRC posts for 1 min generated bond strength to resin-matrix similar to that recorded with a higher concentration, 50% H_2O_2 for longer exposure time (5 and 10 min).
- The bond strength of resin composite to the GFRC post was improved after treatment with 24% or 35% H_2O_2 resulting in bond strength values of 18.7 ± 3.7 and 21.1 ± 4.1 MPa, respectively [20].

Discussion

The present scoping review reported the major results of relevant previous studies taking into account the effect of hydrogen peroxide on the surface topography and bond strength of GFRC posts to resin-matrix cements. In fact, the etching procedure with hydrogen peroxide modifies the surface of GFRC posts and improve the bond strength between the GFRC post and the resin-matrix cement. Thus, the null

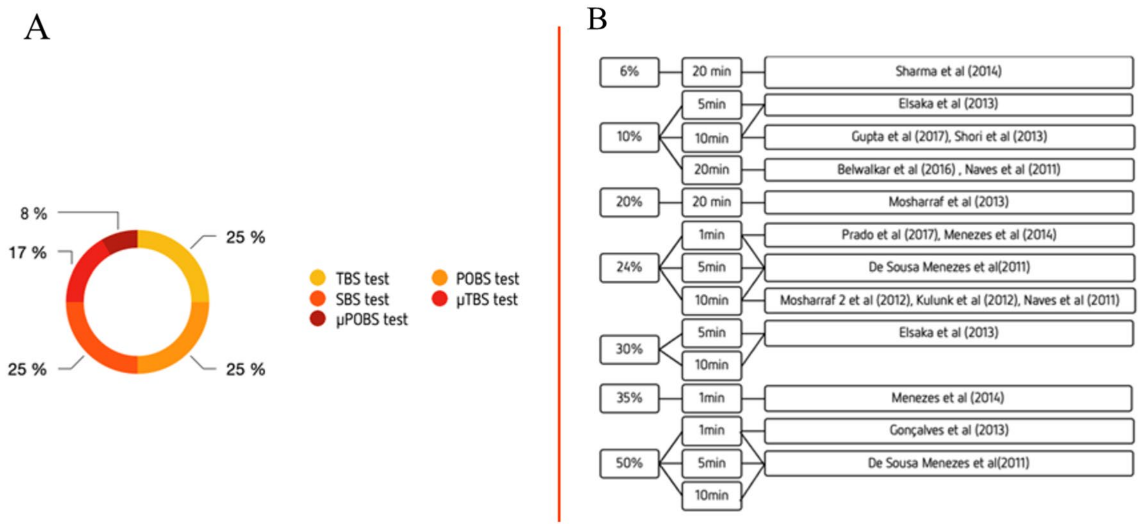

Fig. 2 **A** Distribution of studies on the type of bond strength tests. **B** Concentration of H_2O_2 solutions and application time

Table 1 Relevant data and results extracted from the selected studies

Author (year)	Purpose	Surface modification	Intracanal post	Resin matrix cement	Methods	Main outcomes
Gupta et al. (2017) [16]	Evaluate the effect of various post-surface treatments on the interfacial strength between the posts and composite materials that are used for building up the core portion	G1: 37% H_3PO_4 for 5 min + silane coupling agent G2: $KMnO_4$ for 10 min + silane coupling agent G3: 10% H_2O_2 for 10 min + silane coupling agent G4 (control group): silane coupling agent	Clear post-tapers (Dentmark Co.)	–	TBS Test (–)	Mean bond strength (MPa) G1: 15.02 G2: 20.46 → Highest bond strength G3: 17.22 G4: 10.82 → Lowest bond strength Chemical treatment protocol significantly affected the mean bond strength of the post and core restoration
Mosharraf et al. (2013) [10]	Evaluate the effect of different surface conditioning on tensile bond strength (TBS) of a glass fiber reinforced post to resin cement	G1: 20% H_2O_2 for 20 min + silane coupling agent for 60 s G2: air bone particle abrasion + silane coupling agent for 60 s G3: silane coupling agent for 60 s G4 (control group): No conditioning	Glass reinforced fiber post (Hetco fiber post; Silicon dioxide 55%, calcium oxide 20%, baron oxide 12%, aluminium oxide 14%, sodium oxide 1%, potassium oxide 1%, magnesium oxide 4%; Hakim Toos, Mashhad, Iran)	Adhesive composite resin cement (10-MDP, DMA, Bis-MPEPP (22 wt%); silanized barium glass fillers (78 wt% fillers)—Panavia F 2.0, Kuraray Medical Inc., Japan)	POBS test (Walt + Bai AG Testing Machines Industriestrass 4, Löhningen, Switzeréland)	Mean bond strength (MPa) G1: Coronal: 21.5365 → Highest bond strength Middle: 19.0880 Apical: 9.1230 G2: Coronal: 18.4550 Middle: 10.1700 Apical: 6.5450 G3: Coronal: 20.5310 Middle: 14.5660 Apical: 6.3020 G4: Coronal: 9.7650 Middle: 9.0770 Apical: 5.5850 → Lowest bond strength Significant difference among H_2O_2 + Silane Group and other three groups.
Shori et al. (2013) [32]	Examine the interfacial strength between fiber post and composite, as core build-up material after different surface treatments of fiber posts	G1 (negative control group): No conditioning G2 (positive control group): silane coupling agent for 60 s G3: 37% H_3PO_4 for 15 s + silane coupling agent for 60 s G4: 10% H_2O_2 for 10 min + silane coupling agent for 60 s	Glass reinforced fiber post (65%reinforced, UDMA resin 20% (FIBRAPOST PLUS-Produits Dentaires SA Vevey Switzerland)	Dual cure composite core material (Bis-GMA, urethane dimethacrylate, and triethylene glycol dimethacrylate. (28 wt%), Barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass, and silica fillers (72 wt% fillers), Multi-core Flow –Ivoclar-Vivadent-Liechenstein)	TBS test (–)	Mean bond strength (MPa) G1: 3.99 → Lowest bond strength G2: 7.68 G3: 10.28 G4: 12.38 → Highest bond strength 10% Hydrogen peroxide had a marked effect on micro tensile bond strength values between the tested materials.

Table 1 (continued)

Author (year)	Purpose	Surface modification	Intracanal post	Resin matrix cement	Methods	Main outcomes
Mosharraf et al. (2012) [15]	Evaluate the effects of some surface treatment methods on the tensile bond strength (TBS) between fiber post and composite core	G1: silane coupling agent for 60 s G2: sand- blasted with 50 µm aluminum oxide particles for 10 s G3: 24% H_2O_2 for 10 min G4 (control group): No conditioning	Glass reinforced fiber post (Exacto Fiber Post; Epoxy 20%; Glass 80%; Angelus, Londrina, PR, Brazil) Hetco fiber post (Silicon dioxide 55%, calcium oxide 20%, baron oxide 12%, aluminium oxide 14%, sodium oxide 1%, potassium oxide 1%, magnesium oxide 4%; Hakim Toos, Mashhad, Iran)	Clearfil Photo core Composite (Bis-GMA, TEG-DMA (30 wt%), silanated barium glass filler (70 wt% fillers), (Clearfil esthetic cement, Kuraray Medical Inc., Tokyo, Japan)	TBS test (Electromechanical low-capacity testing Machines, walter + bai, AG, Switzerland) Failure analysis: Stereomicroscope (MBC, 10 Number: n 9116734 SF- 100B, LOMO, Russia)	Mean bond strength (MPa) Exacto Fiber G1: 14.1550 → Highest bond strength G2: 12.9400 G3: 9.8800 → Lowest bond strength G4: 12.4450 Hetco Fiber G1: 14.3875 → Highest bond strength G2: 12.8762 G3: 9.8150 → Lowest bond strength G4: 11.5138 Significant difference between H_2O_2 and Silane conditioning groups and between H_2O_2 and gritblasting groups. Two types of fracture mode: Adhesive between post and core and cohesive in the core material. None of the test groups demonstrated cohesive failure within the post material. Silane and grtiblasting groups: most of the fractures were cohesive H_2O_2 and control groups: predominant fracture pattern was adhesive failure
Prado et al. (2017) [14]	Evaluate the effect of different surface treatments on fiber post cemented with a self-adhesive system	G1 (control group): No conditioning G2: silane coupling agent 60 s G3: 24% H_2O_2 for 1 min G4: sandblasting with aluminum oxide for 30 s G5: NH_3 plasma for 3 min G6: HMDSO plasma for 15 min	Glass reinforced fiber post (White Post DC3; 80% glass fiber and 20% epoxy resin; FGM, Joinville, SC, Brazil)	Resin cement (Methacrylate monomers containing phosphoric acid groups, methacrylate monomers (28 wt%), silanated fillers, alkaline fillers (72 wt% fillers), RelyX U200, 3 M ESPE, St. Paul, MN, USA)	POBS test (DL 1000, Emic, São José dos Pinhais, PR, Brazil) Failure analysis: Stereomicroscope (SMZ800, Nikon Instruments, São Paulo, SP, Brazil) Surface topographical analysis: SEM evaluation (JSM 6460 LV (JEOL, Tokyo, Japan)	Mean bond strength (MPa) G1: 9.648415 G2: 15.935862 → Highest bond strength G3: 9.400132 → Lowest bond strength G4: 13.133998 G5: 14.441980 G6: 14.441980 Silane, gritblasting, NH_3 plasma and HMDSO plasma showed higher POBS when compared to control. Gritblasting and H_2O_2 showed the degradation of the epoxy resin matrix and exposed fibers with no apparent fiber damage.

Table 1 (continued)

Author (year)	Purpose	Surface modification	Intracanal post	Resin matrix cement	Methods	Main outcomes
Belwalkar et al. (2016) [33]	Compare the effect of four chemical surface treatments of a GFP on adhesion with a resin-based luting agent	G1: (control group) silane coupling agent for 60 s G2: 20% $KMnO_4$ + silane coupling agent for 60 s G3: 4% HF for 60 s + silane coupling agent for 60 s G4: 10% H_2O_2 for 20 min + silane coupling agent for 60 s	Glass reinforced fiber post (D. T. Light-Post; Quartz 60%, Resin epoxy 40%; Bisco, Inc., Schaumburg, IL, USA)	Calibra light shade base and regular viscosity catalyst (Dentsply, Caulk, Milford, U.S.A)	SBS test (Instron 4467; Instron Corp, Norwood, Mass)	Mean bond strength (MPa) G1: 16.421 → Lowest bond strength G2: 27.233 → Highest bond strength G3: 21.781 G4: 19.037 Highly significant difference between the tested groups. Combination of chemical pre-surface treatment followed by silanization significantly enhanced the bond strength at the post/adhesive interface.
Sharma et al. (2014) [34]	Evaluate effect of newer chemical solvents, i.e., 6% hydrogen peroxide and 37% phosphoric acid on shear bond strength of glass fiber posts to core material	G1: (control group) silane coupling agent for 60 s G2: 6% H_2O_2 for 20 min + silane coupling agent for 60 s G3: 37% H_3PO_4 for 20 s + silane coupling agent for 60 s	Glass fiber post (–)	–	SBS test (–) Surface topographical analysis: SEM evaluation (LEO 430, LEO Electron Microscopy Ltd, Cambridge, UK)	Mean bond strength (MPa) G1: 19.41 → Lowest bond strength G2: 25.52 → Highest bond strength G3: 21.14 Surface treatment with hydrogen peroxide had greatest impact on the post surface followed by 37% phosphoric acid and silane. The post surface morphology was modified, and surface treatment dissolved the epoxy resin matrix and exposing the quartz and glass fibers in the posts. G1: Less exposed fibers after treatment G2: More exposed fibers after treatment G3: More exposed fibers compared to G1 (control group) but less exposed fibers in comparison to G2

Table 1 (continued)

Author (year)	Purpose	Surface modification	Intracanal post	Resin matrix cement	Methods	Main outcomes
De Sousa Menezes et al. (2011) [17]	Evaluate the effect of concentration and application time of hydrogen peroxide on the surface topography and bond strength of glass fiber posts to resin cores	G1: (control group): No conditioning G2: 24% H_2O_2 for 1 min + silane coupling agent for 60 s G3: 24% H_2O_2 for 5 min + silane coupling agent for 60 s G4: 24% H_2O_2 for 10 min + silane coupling agent for 60 s G5: 50% H_2O_2 for 1 min + silane coupling agent for 60 s G6: 50% H_2O_2 for 5 min + silane coupling agent for 60 s G7: 50% H_2O_2 for10 min + silane coupling agent for 60 s	Quartz reinforced fiber post (Aestheti-Plus; Quartz fibers 60% embedded in an epoxy resin matrix 40%; Bisco, Schaumburg, IL, USA)	Core-Flo DC, composite resin, dual-cured (Ethoxylated Bis A Dimethacrylate, Bis-GMA, silica, glass fillers (50–75 wt%) Bisco Inc, Schaumburg, IL, USA)	µTBS Test (DL 2000; EMIC, Sao Jose dos Pinhais, PR, Brazil) Surface topographical analysis: SEM evaluation (JSM-5600LV; JEOL, Tokyo, Japan)	Significant difference among the groups treated with hydrogen peroxide (G2–G3–G4–G5–G6–G7) and the control group (G1) No significant differences for the factor ''concentration of H_2O_2'', ''application time'', or the interaction between the factors (no significant difference among the groups treated with hydrogen peroxide.) Both 24% and 50% hydrogen peroxide increased the bond strength of resin to the posts. Application of hydrogen peroxide increased the roughness and exposed the fibers for all concentrations and application times. The exposed glass fibers were not damaged or fractured by any etching protocol.
Kulunk et al. (2012) [18]	Evaluate the effect of mechanical and chemical surface treatment methods on the bond strength of resin cement to fiber post	G1: (control group) silane coupling agent for 60 s G2: CH_2Cl_2 for 5 s + silane coupling agent for 60 s G3: 24% H_2O_2 for 10 min + silane coupling agent for 60 s G4: air abrasion with 30 mm aluminum oxide particles modified by silica (SiOx) + silane coupling agent for 60 s G5: air abrasion with 50 mm alumina oxide particles (Al_2O_3) + silane coupling agent for 60 s G6: air abrasion with 1–3 mm synthetic diamond particles (Micron + MDA) + silane coupling agent for 60 s	Quartz reinforced fiber post (Light-Post; 2-stage, translucent fiber post 62% Quartz Fiber, 38% Epoxy Resin; Bisco, Schaumburg, USA)	Adhesive composite resin cement (Panavia F 2.0; ED Primer 2: adhesive phosphate monomer (MDP), HEMA and water Dual-cure resin cement: MDP, comonomers, fillers, initiators and functional sodium fluoride; Kuraray, Okayama, Japan)	Push out test (Lloyd LRX; Lloyd Instruments PIC, Fareham, Hampshire, UK) Failure analysis: Stereomicroscope (Leica, MZ125, Milton Keynes, UK) Surface topographical analysis: SEM evaluation (JSM_6335F; JEOL, Tokyo, Japan)	Mean bond strength (MPa) G1: 6.49 → Lowest bond strength G2: 7.22 G3: 9.13 G4: 10.78 G5: 11.73 G6: 13.66 → Highest bond strength Application of hydrogen peroxide resulted in higher push-out bond strength values than the other chemical surface pre-treatment methods. The majority of failures were adhesive failure. Application of surface pre-treatment affected the surface morphology of quartz fiber posts. Silane treatment has no significant effect on the surface of quartz fiber post when compared with other surface pretreatment methods. Silica coating with 30 mm SiOx and air abrasion with 50 mm Al_2O_3 particles removed the epoxy resin matrix and fractured quartz fiber in some areas.

Table 1 (continued)

Author (year)	Purpose	Surface modification	Intracanal post	Resin matrix cement	Methods	Main outcomes
Menezes et al. (2014) [20]	Evaluate the effect of the concentration and application mode of hydrogen peroxide on the surface topography and bond strength of resin composite to glass- fiber posts	G1 (control group): No conditioning G2: Immersion of 24% H_2O_2 for 1 min + silane coupling agent for 60 s G3: Application of 24% H_2O_2 for 1 min + silane coupling agent for 60 s G4: Immersion of 35% H_2O_2 for 1 min + silane coupling agent for 60 s G5: Application of 35% H_2O_2 for 1 min + silane coupling agent for 60 s	Glass reinforced fiber post (WhitePost DC3, 80% glass fiber; 20% epoxy resin FGM, Joinvile, SC, Brazil)	Microhybrid resin composite, Opallis, (Matrix: Bis-GMA, Bis-EMA, TEG-DMA Filler: 40 nm-3.0 µm with a mean particle siez of 0.5 µm (57vol%); FGM Dental Products,Joinville, SC, Brazil)	µTBS Test (EMIC DL 2000, Sao Jose dos Pinhais, PR, Brazil) Surface topographical analysis: SEM evaluation (LEO 435 VP, Nano Technology Systems Division of Carl Zeiss SMT, Cambridge, UK)	Mean bond strength (MPa) G1: 11.0 → Lowest bond strength G2: 18.7 G3: 13.4 G4: 21.1 G5: 21.0 Immersion of the post into H_2O_2 solutions: no difference between concentrations, although using 35% H_2O_2 resulted in higher bond strength. Application of H_2O_2: Except for the application of 24% H_2O_2, the other experimental conditions resulted in higher bond strength than the control. More exposed fibers were noticed when the post was etched by immersion in H_2O_2 (both concentrations) and when 35% H_2O_2 was applied. The application of 24% H_2O_2 on the post surface did not effectively expose the glass fibers.
Gonçalves et al. (2013) [19]	Influence of chemical cleaning agents on the bond strength between resin cement and glass-fiber posts	G1(control group): silane coupling agent for 60 s G2: 10% HF for 60 s + silane coupling agent for 60 s G3: 35% H_3PO_4 for 60 s + silane coupling agent for 60 s G4: 50% H_2O_2 for 60 s + silane coupling agent for 60 s G5: C_3H_60 for 60 s + silane coupling agent for 60 s G6: CH_2Cl_2 for 60 s + silane coupling agent for 60 s G7: C_2H_60 for 60 s + silane coupling agent for 60 s G8: C_3H_80 for 60 s + silane coupling agent for 60 s G9: C_4H_80 for 60 s + silane coupling agent for 60 s	Glass-fiber epoxy specimens (Glass fiber 80%, epoxy resin 20%; Angelus (Londrina, PR, Brazil)	Dual-cure resin cement base and catalyst paste (Methacrylate monomers containing phosphoric acid groups, methacrylate monomers (28 wt%), silanated fillers (72 wt% fillers), RelyX ARC; 3 M ESPE, St. Paul, USA)	SBS Test (DL500; EMIC, São José dos Pinhais, Brazil) Failure analysis: stereomicroscope (–)	All chemical agents provided significantly increased bond strength compared with the control group. The bond failures were exclusively adhesive (interfacial) in all groups, with no residual resin cement left on the post surface after debonding.

Table 1 (continued)

Author (year)	Purpose	Surface modification	Intracanal post	Resin matrix cement	Methods	Main outcomes
Naves et al. (2011) [6]	Evaluate the effect of different chemical etching procedures on the surface characteristics of carbon and glass/epoxy fiber-reinforced resin posts	G1: (control group): No conditioning G2: 24% H_2O_2 for 10 min G3: 10% H_2O_2 for 20 min G4: 4% HF gel for 60 s G5: 37% H_3PO_4 gel for 30 s	Glass fiber post, Gfp (85% quartz fiber, 15% epoxy resin Reforpost Glass, Angelus, Londrina, Parana, Brazil) Carbon fiber post, Cfp (62% carbon fiber, 38% epoxy resin; Reforpost Carbon; Angelus)	–	Surface topographical analysis: SEM evaluation (LEO 435 VP; LEO Electron Microscopy Ltd., Cambridge, UK)	G1/Gfp and Cfp: rough surface with fibers covered by epoxy resin. G2–G3/Gfp and Cfp: dissolution of epoxy resin and exposure of the superficial fiber. G4/Gfp: HF seems to penetrate around the fibers and promoted surface alterations with the presence of by-product precipitate along the resin matrix-glass fiber interface. G4/Cfp: The surface of post seems to be inert to treatment with 4% HF. The epoxy matrix also seems unmodified after the same treatment G5/Gfp and Cfp: Relative smooth surface area was produced, but with similar features to untreated group.

Table 1 (continued)

Author (year)	Purpose	Surface modification	Intracanal post	Resin matrix cement	Methods	Main outcomes
Elsaka et al. (2013) [2]	Evaluate the effect of fiber post surface treatment with CH_2Cl_2 and H_2O_2 on the morphological aspects of the post surface, and the influence of different surface treatments on the micropushout bond strength of fiber posts to different composite resins for core-build up	G1(control group): No conditioning G2: silane coupling agent for 60 s G3: 10% H_2O_2 for5min G4: 10% H_2O_2 for10min G5: 30% H_2O_2 for5min G6: 30% H_2O_2 for10min G7: CH_2Cl_2 for10min G8: CH_2Cl_2 for 5 min	RP: Reblida post (70% glass fiber, 10% filler, 20% UDMA) VOCO, Cuxhaven, Germany RX: RelyX post (Glass fiber reinforced Composite, methacrylate resin) 3 M ESPE, St. Paul, MN, USA	GR: dual cure composite core, Grandio Core DC (Matrix: Bis-GMA, UDMA resins Filler: silica/Ba-glass ceramics (77%, wt). Amines, benzoyl peroxide, BHT) VOCO, Cuxhaven, Germany F60: composite resin material, Filtek P60 (Matrix: Bis-GMA, UDMA, Bis-EMA resins Filler: zirconia/silica (61%, vol., 83%, wt). Particle size range of 0.01–3.5 _m. Initiators, inorganic pigments) 3 M ESPE, St. Paul, MN, USA	µPush out test (Model TT-B, Instron Corp., Canton, MA, USA) Failure analysis: stereomicroscope (Olympus SZX-ILLB100-Olympus Optical Co. Ltd., Tokyo, Japan) Surface topographical analysis: SEM evaluation (JEOL; JXA-840A, JEOL, Tokyo, Japan)	Mean bond strength (MPa) G1 G4 G7 RP/GR: 16.2 RP/GR: 20.8 RP/GR: 25.9 RP/F60:9.4 RP/F60: 11.1 RP/F60: 18.3 RX/GR:12.1 RX/GR: 16.3 RX/GR: 19.8 RX/F60: 10.0 RX/F60: 11.9 RX/F60: 18.5 G2 G5 G8 RP/GR: 17.4 RP/GR: 23.2 RP/GR: 26.4 RP/F60: 9.6 RP/F60: 16.9 RP/F60: 20.3 RX/GR: 12.2 RX/GR: 18.5 RX/GR: 21.1 RX/F60: 10.2 RX/F60: 17.2 RX/F60: 19.4 G3 G6 RP/GR: 18.9 RP/GR: 24.4 RP/F60: 10.1 RP/F60: 17.5 RX/GR: 13.3 RX/GR: 20.3 RX/F60: 11.4 RX/F60: 18.3 The bond strength was significantly affected by the type of fiber post. 30% H_2O_2 for 5 and 10 min were significantly higher compared with the control and silanization groups for both types of posts with the core materials tested. Most failure modes were adhesive type of failures between post and core material (93.5%). In addition, mixed failures (5.1%), cohesive failures within the core material (1.1%), and cohesive failures within the post (0.3%) were also detected. H_2O_2 and CH_2Cl_2 groups The surface treatments dissolved the resin matrix of the posts and exposed the glass fibers of the posts. The exposed glass fibers were not damaged or fractured by the surface treatment.

hypothesis tested was rejected and therefore a detailed discussion of recent findings is provided as follow.

Despite the advantages of GFRC posts, several studies report debonding as a frequent complication. Debonding is the most common type of failure as a consequence of the GFRC post design (shape, length, diameter), resin-matrix cement, and interaction between adhesive surfaces (Fig. 3A–C) [21–23]. Several in vitro studies have confirmed the importance of the remaining bulk of tooth structure on the overall strength. Therefore, post diameter must be controlled to preserve radicular dentin, decreasing the potential for root perforations [22, 24, 25]. Previous studies have reported results from push-out bond strength tests that are performed using a universal testing machine. Loading is applied onto the cross-sectioned specimens at crosshead speed of 0.5 or 1 mm/min from apical to coronal direction until adhesion failure, as reported by a recent study [26]. The fracture load is recorded in N while the strength values are recorded in MPa.

Hydrogen peroxide (H_2O_2) is the simplest member of the class of peroxides (a chemical with an oxygen–oxygen single bond). It has chemical applications and therapeutic use, including as an antimicrobial and oxidizing agent [27]. Indeed, hydrogen peroxide is commonly utilized in immunological electron microscopy to partially dissolve the surface of epoxy-embedding tissue sections and expose tissue epitopes for immunolabeling enhancement. A similar H_2O_2 etching procedure may be applied to improve the mechanical retention between the epoxy matrix of GFRC posts and methacrylate-based resin composites (Fig. 3).

Fiber integrity and homogeneity along a treated surface with hydrogen peroxide was thoroughly analyzed by [2, 6, 14, 18]. Non-abraded GFRC posts had a relatively smooth surface area, with limited mechanical interlocking between the GFRC post surface and resin-matrix cement. The H_2O_2 etching has promoted the morphological change of the GFRC post surface by the dissolution of epoxy resin and exposure of the outer fibers, resulting in a rough surface (Fig. 3). Exposed fibers did not appear to be damaged by the action of hydrogen peroxide and no defects or fractures were evident on their surfaces [2, 6, 14, 16]. A homogenous distribution of micro-spaces was evident among the exposed fibers. The spaces created between these fibers provide additional sites for mechanical retention of the resin-matrix composites [6]. Such retention concept is reminiscent of the establishment of hybrid layers in dentin, as the interface is formed by both the fibers and the methacrylate matrix [7].

However, the use of peroxides during endodontic procedures might compromise the adhesive cementation of posts. Such effect is attributed to the presence of residual oxygen into dentinal tubules interfering with the polymerization of the adhesive resin. However, some authors have found that etching with H_2O_2 in combination with a coupling agent increases the bond strength of the adhesive core of resin-matrix composites to GFRC posts [10, 14, 16, 28]. The deleterious effect of the peroxide was probably not detected because of the absence of residual oxygen into the post structure [17].

The results reported by Prado et al. [14] and Mosharrraf et al. [15] were inconsistent with the evidence found in other studies. Prado et al. [14] evaluated the effect of different surface treatment (i.e. Silane, H_2O_2, gritblasting, NH_3 plasma, HMDSO plasma) on GFRC post cemented with a self-adhesive system and therefore the surface treatment with 24% hydrogen peroxide for 1 min showed push-out bond strength values statistically similar to the control. The inferior results of H_2O_2 when compared with other treatments can occur due to surface morphological aspects and the interaction of H_2O_2 with resin-matrix cement. Similary, Mosharraf et al. [15] evaluated the effects of some surface treatment methods (i.e., Silane, gritblasting, H_2O_2) on the tensile bond strength between GFRC post and composite core and therefore the application of H_2O_2 for 10 min had no significant effects on bonding strength. Indeed, the H_2O_2 group had the least tensile bond strength mean values even in comparison with the control group. That can occur due to the bonding immediately after H_2O_2 application (without silane coupling agent as a mediator). The controversy and inconsistency of the findings of previous studies are related to differences in surface treatment protocols, type of posts, core materials, and methods of testing [15]. Thus, the oxidizing effect of H_2O_2 and its ability to affect the bond strength of the GFRC posts to the resin-matrix materials would depend on several factors such as concentration of radicals without oxygen, hydrogen, water and peridroxyl as well as its time and mode of application [20].

The effect of GFRC post surface treatment with CH_2Cl_2 and 10 or 30% H_2O_2 for 5 and 10 min was evaluated on the morphological aspects of the post surface. The push-out bond strength of GFRC posts to different resin-matrix composite for core-build up revealed that 10% H_2O_2 surface treatment for 5 or 10 min did not have a significant effect on the post/core bond strength.

Another study evaluated the effect of two concentration (24% and 50%) and application time (1, 5, 10 min) of hydrogen peroxide on the surface topography and bond strength of GFRC posts to resin composite cores. Both 24 and 50% H_2O_2 concentrations were able to partially dissolve the epoxy resin and expose the glass fibers after a 1 min conditioning. The slight etching by 24% H_2O_2 after 1 min exposure was sufficient to result in bond strength similar to that recorded with higher concentrations or longer application time. The concentration and application time of H_2O_2 did not affect the bond strength values. Based on the previous results, the lower concentration 24% H_2O_2 used for just 1 min is preferable in clinical use [17].

The effect of the concentration (24% and 35%) and application mode (i.e., immersion, application) of hydrogen peroxide on the surface topography and bond strength of resin-matrix composite to GFRC posts was examined by another previous study [20]. In fact, 35% H_2O_2 is effective on improving bond strength independent of the application mode. To the contrary, 24% H_2O_2 increased the bond strength of resin composite to GFRC post only when the post was immersed in solution. A thin layer of hydrogen peroxide applied on the post only reacted with the epoxy resin on surface once there was no replacement of radicals by oxidation. The replacement of radicals probably occurred when the post was immersed in 24% H_2O_2 solution, thus increasing the potential for etching.

After performing the bond strength test, five studies [2, 18–20] examined the surfaces using a stereomicroscope at different magnifications in order to classify the mode of failure. Failures are distributed as: post cohesive (failure located within the post structure), resin cohesive (failure located within the resin-matrix composite structure), adhesive (failure at the interface between the post and resin-matrix composite) or mixed (when more of a type of failure can be detected in the same sample).

Failure mode analysis has revealed that adhesive failure between the GFRC post and luting cement was the predominant failure pathway. Those results are in disagreement with another previous study since they reported the predominant mode of failure was cohesive within the post and the cement [2, 15, 18, 20].

Adhesive failures may have several causes, including root canal shape, difficulty in accessing the middle and apical root thirds, the different histology of the root dentin (quantity and direction of the dentin tubules), and low intensity of light curing in the middle and apical thirds. In addition, there is the polymerization shrinkage that generates a stress at the adhesive interface causing microgaps and negatively influences the bond strength values [29, 30]. High bond strength between resin composite and GFRC posts is desirable. However, the debonding of the GFRC post from the core could be clinically more favorable failure mode than fracture of the GFRC post. The fracture of the resin composite core could be repaired by adding resin composites while a GFRC post fracture can only be repaired by entirely removing the fractured post, which is a more challenging procedure, and associated with some risk of root perforation and weakening of the root structure [2].

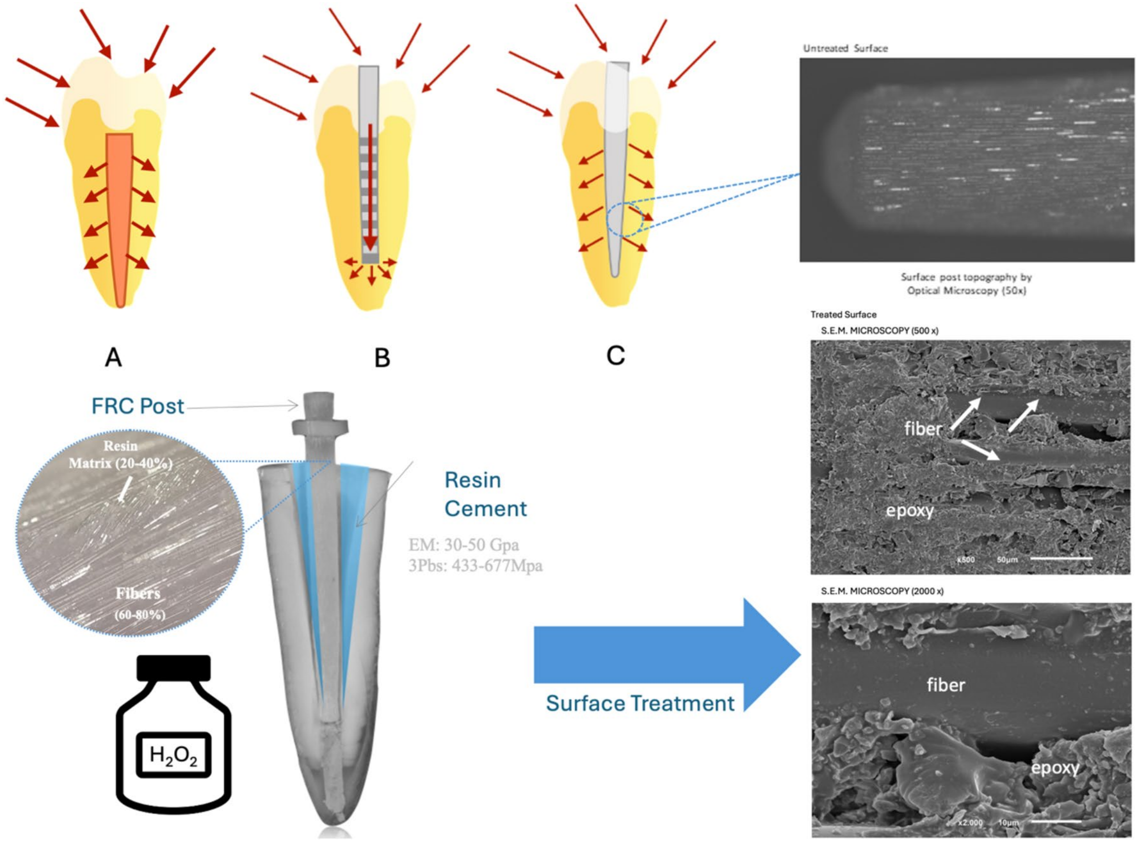

Fig. 3 **A**–**C** Schematics of the stress distribution. **A** Tooth core with fiber-based or **B** metal post. Surface treatment by H_2O_2 solution (below). Representative SEM images: Surface after etching with 50% H_2O_2 for 1min; or 24% H_2O_2 for 5min (right side)

Regarding the included studies, all published articles are based on in vitro investigations [31]. The findings do not give an exact prediction whether the in vitro performance of the GFRC posts is the same as the clinical performance [5]. Thus, in vivo studies are required to evaluate whether the positive performance of the treated GFRC posts is similar as the performance in vitro [2]. According to the results described in the Table 1, it can be noted that there is no coherence between the mean values of bond strength (in MPa) recorded in the analyzed articles. In vitro guidelines should be quite similar to provide comparison of results.

Future studies with larger study groups are also required for further exploration of this field of restorative dentistry, so as to establish certain precise guidelines in such perspective [16]. Most of studies assessed only one type of resin cement or GFRC post. Different results might be acquired with different types of resin-matrix cements, GFRC posts, in different storage conditions. Besides, the effect of surface pretreatment methods on the mechanical properties of GFRC posts might be evaluated. The selected studies have been primarily performed using bond strength tests in combination with microscopic analysis. The surface characteristics of the posts have been analyzed only by scanning electron microscopy. Additional analyzes should be done such as surface roughness of GFRC posts measured with an optical profilometer. Finally, the pre-treatment of the GFRC post should be immediately followed by the application of the resin-matrix composite for the core build-up. Further in vitro and in vivo studies are required to evaluate whether the positive effect on post-core bond strength is still retained by pretreating the post surface. Evaluation of such a strategy will enable manufacturers to supply pretreated GFRC posts as well as saving clinicians valuable chair-side time.

Conclusions

Within the limitations of the in vitro selected studies, the following concluding remarks can be drawn as follow:

- Conditioning of GFRC posts using hydrogen peroxide acts by removing a surface layer of epoxy matrix and, therefore, exposing larger surface area of fibers for further silanization.
- Hydrogen peroxide conditioning is an effective and clinically feasible method for enhancement of interfacial strengths between glass fiber-reinforced composite posts and resin composite cements, without utilizing extremely corrosive liquids in a clinical setting.
- Further evaluations on factors such as concentration, exposure time, and mode of application are required before promoting any clinical recommendations.

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Data Availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interests.

Ethical Approval Not applicable.

Informed Consent Not applicable.

Research Involving Human and Animal Rights The present review does not involve any human or animal participants.

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