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Review

Effect of Enamel Bleaching on the Bond Strength of Ceramic—A Systematic Review

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Abstract: The increase in aesthetic demands has increased the use of ceramic dental restorations in dentistry. Ceramic restorations are bonded to the tooth structure using adhesives. There is a lack of standard guidelines in terms of post-bleaching time intervals and bond strengths of ceramic restorations. Bleaching products have also been stated to affect the morphology of enamel. Therefore, the purpose of this systematic review is to evaluate the bond strength between ceramic and enamel and the changes in the surface roughness of enamel post teeth bleaching. An electronic search was performed in the databases PubMed, OVID MEDLINE, Scopus, and Web of Science with MESH terms: "adhesion OR bonding", "ceramic OR ceramics OR dental porcelain", "tooth bleaching OR teeth bleaching OR tooth whitening OR teeth whitening" and "enamel OR dental enamel OR enamels OR dental enamels". The articles were screened, and the final selection of articles was obtained by using the inclusion and exclusion criteria. Of the 170 studies identified from the search, only 12 studies met the inclusion criteria and were selected for full-text review. A further search by hand was performed, and additional 48 studies were selected. From the 60 full-text studies, 18 studies met the inclusion criteria and were included for data extraction. The results were based on a descriptive analysis of the effect on bond strength of ceramic to enamel after a bleaching protocol and the changes in the surface roughness of enamel post bleaching protocol. In conclusion, bleaching protocols alter the surface roughness of enamel and, thus, the shear bond strength between ceramic and enamel. Bleaching treatments with a higher concentration of hydrogen peroxide reduce the bond strength between ceramic and enamel. Delaying bonding after bleaching for up to 7 days increases the bond strength between ceramic and enamel.

Keywords: dental enamel; teeth bleaching; teeth whitening; roughness; bond strength; adhesive restorations; dental materials

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1. Introduction

With increased knowledge of aesthetics and patient demand for a perfect smile, ceramic restorations and teeth whitening have become popular treatment options in aesthetic dentistry. Tooth whitening, especially, became popular with the increased number of at-home and in-office bleaching products available in the market [1–3]. Bleaching is a conventional, simple, and economical treatment option available for changing the colour of teeth and improving the harmony of the smile [4]. The first known article related to home bleaching techniques using carbamide peroxide was published in 1989 [5]. Since then, many novel systems have been introduced to the market with various concentrations of bleaching agents, including carbamide peroxide and hydrogen peroxide [6,7]. The mechanics of teeth whitening is that hydrogen peroxide (which is also produced when carbamide peroxide reacts with water) molecules penetrate through the enamel and oxidise the organic materials, reducing colour and bleaching the tooth [8]. Despite its clinical success and high patient acceptance, tooth bleaching obviously raises concerns among dental practitioners since it may not only weaken enamel and dentine but also alter the bond strength of both composite and ceramic restorations [9–11]. While more rapid bleaching of teeth is available with dental practitioners, with 25–40% concentrations of peroxide or carbamide, lower concentrations of 3–25% are available for use at home [2,12]. However, previous studies have shown that when a 35% concentration of hydrogen peroxide is used, it may alter enamel composition and structure [13,14].

Past studies have reported that weakened enamel due to bleaching decreases its bond strength to restorative materials and impacts the surface roughness [15], morphology [16,17] and microhardness [18–20] of human enamel [21]. Studies have also found alterations in enamel structure (with an increase in surface roughness) and in the depth of grooves after bleaching procedures [22–24]. However, some studies found minimal or no effect on the surface morphology of enamel after bleaching procedures [25–27]. The hydrogen peroxide in bleaching products alters the calcium-to-phosphate ratio within the enamel and forms porosity on superficial enamel and the loss of prismatic form [15–18]. The oxygen in hydrogen peroxide is absorbed into the tooth enamel and, as a result, into the dentine before being released through surface diffusion and accumulating within the enamel structure, reducing the bond strength of resin-based restorative materials [28,29].

The preferential use of aesthetic dental materials for restorations due to the increase in the aesthetic demands of patients has led to an increase in ceramic systems, especially ceramic crowns [30–32]. The bonding strength of resin to enamel is dependent on the time of bonding after bleaching [33]. The low shear bond strength between resin and enamel is shown in the first two weeks after bleaching [33]; however, the reduction of bond strength between resin and enamel is more significant in the first 24 h post bleaching [11]. The study by Cavalli et al., (2001) [33] showed that after vital bleaching with hydrogen-peroxide- and carbide-peroxide-based bleaching agents, it takes almost three weeks for the resin–enamel bond strength values to return to unbleached enamel values. This was also investigated by Basting et al., (2003) [34]. The reduction in bonding between ceramic restoration and enamel post bleaching is a concern in aesthetic dentistry, where vital bleaching is required to improve the appearance of teeth preceding the bonded restoration [34].

The study by Rahul et al., (2017) [35] evaluated the shear bond strength of at-home and in-office bleaching agents and found that using an in-office bleaching technique 24 h prior to the bonding procedure significantly reduced the shear bond strength between ceramic and enamel, whereas at-home bleaching agents did not have any significant effect on bond strength [34]. Similar findings were also reported by Nilgum et al., (2011), who found a significant reduction in the micro tensile bond strength between enamel and ceramic laminate veneers [36]. The investigators further stated that an important factor in the effectiveness of the bonding of ceramics is the bleaching procedure [37]. However, Oztas et al., (2012) did not find any significant difference within 24 h or 14 days after bleaching in the shear bond strength of ceramic orthodontic brackets within two groups of chemically and light-cured composite resins attached to enamel [37]. The study conducted by Firoozmand et al., (2013) further reported that in addition to the type of bleaching treatment, the type of bonding resin also affects the bonding strength of restorations [38].

The increase in aesthetic demands has increased the use of ceramic dental restorations in dentistry. Ceramic restorations are bonded to the tooth structure using adhesives. There is a lack of standard guidelines in terms of post-bleaching time intervals and the bond strength of ceramic restorations. Bleaching products have also been stated to affect the surface morphology of enamel. Therefore, the purpose of this systematic review is to evaluate the bond strength between ceramic and enamel and the changes in surface roughness of enamel post teeth bleaching.

2. Materials and Methods

2.1. Search Strategy

A search was performed in the PubMed, OVID MEDLINE, Scopus, and Web of Science databases with MESH (Medical Subject Headings) terms: “adhesion OR bonding”, “ceramic OR ceramics OR dental porcelain”, “tooth bleaching OR teeth bleaching OR tooth whitening OR teeth whitening” and “enamel OR dental enamel OR enamels OR dental enamels”. The search strategy focused on patient, intervention, comparison, and outcome PICO criteria, and the focus questions are presented in Table 1.

Table 1. Focus questions and PICO criteria.

Focus Questions	1. Does Bleaching Cause the Surface Roughness of Enamel? 2. Does Bleaching Affect the Bonding Strength of Ceramic?
PICO Criteria	
Population	Extracted human teeth or bovine teeth or enamel slab
Intervention	Tooth bleaching using hydrogen peroxide or carbamide peroxide with different concentrations
Comparison	Unbleached enamel
Outcome	Shear bonding strength, tensile bond strength, change in surface roughness

Database searches were restricted to the English language, in vitro studies, in vivo studies, randomised control trials, case–control studies, and studies with commercially available products. The search includes all available scientific evidence in PubMed, OVID Medline, Scopus, Web of Sciences databases up to February 2022. Further hand searches of studies identified from the bibliographies of relevant studies were conducted. Following the inclusion and exclusion criteria, the studies were then included or excluded from the total studies identified (Table 2).

Table 2. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
English language only Full text only In vitro studies In vivo studies Case–control studies Commercially available products Randomised control trial	Studies in a language other than English Abstract only Studies irrelevant to the focus questions Review articles Case reports Conference paper Technique article Studies with a sample size of <10 extracted teeth

2.2. Selection of Studies

Potential studies were assessed independently by three reviewers (I.S., A.G., J.J.E.C.) following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [39]. After applying the exclusion and inclusion criteria, full-text studies were elected for both reading and final selection. All differences in the selection of the articles between the three authors were analysed, and agreement was established through discussion, as per the PRISMA guidelines.

3. Results

Of the 170 studies identified from the search, only 12 studies met the inclusion criteria and were selected for full-text review based on the information given in the abstract. A further hand search was performed from the citations of the 12 studies, and 48 additional studies were selected for full-text review. Only 18 of the 60 full-text studies met the inclusion criteria and were included in the data extraction process (Figure 1).

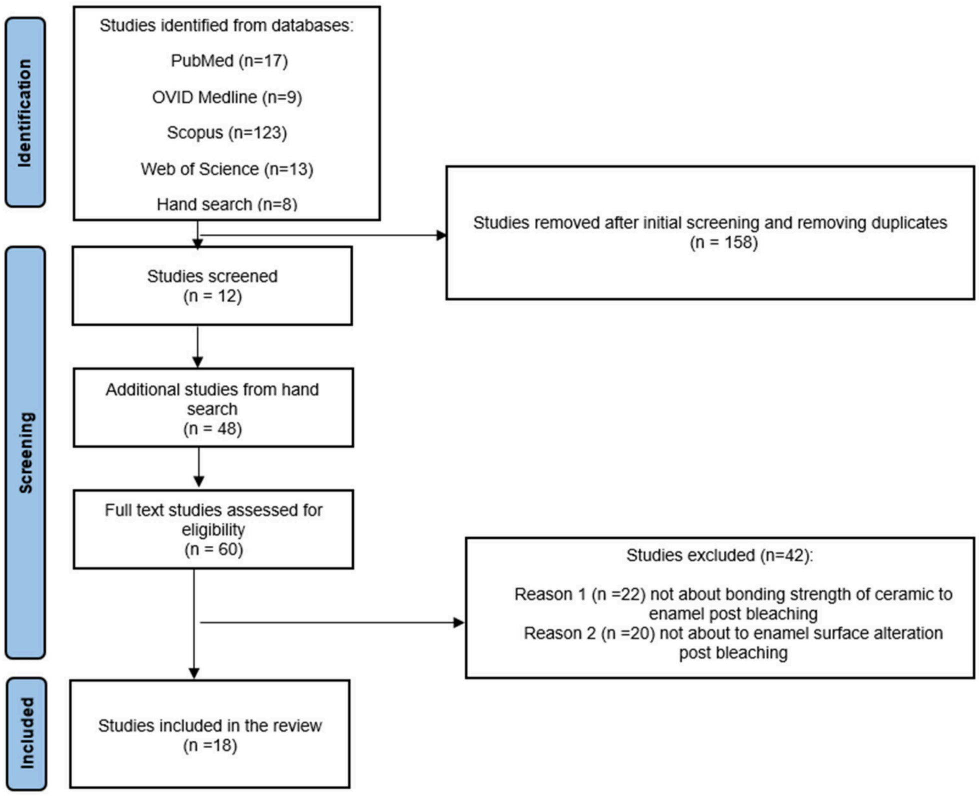

Figure 1. PRISMA flow diagram summarising the selection process.

3.1. Effect on Bond Strength of Ceramic to Enamel after Bleaching Protocol

Of the 18 studies included in the review, a total of 9 studies evaluated the bond strength of ceramic to enamel after bleaching protocols [35–38,40–44] (Table 3). Three studies that used a 10% carbamide peroxide bleaching agent did not find any significant difference in shear mean bond strength values between enamel and ceramic after the application of the bleach for either 10, 20, or 30 s [41] when bonding was done directly after bleaching [42] and 24 h after the bleaching procedure [35]. Similarly, Öztas et al., (2011) did not find any significant difference in the shear bond strength of ceramic orthodontic brackets bonded with either chemically or light-cured composite resins to enamel both 24 h and 14 days after bleaching with 20% carbamide peroxide [37]. However, a study that used 35% hydrogen peroxide bleach recorded an increase in the shear bond strength of ceramic brackets bonded to the enamel with an application of desensitising agent after bleaching when compared to a specimen that had not undergone any bleaching protocol at all and also when compared to a specimen with three applications of 35% hydrogen peroxide bleach for 15 min [40]. Similarly, Gökce et al., (2008) also showed significantly higher bond strengths in samples with an antioxidant application (10% sodium ascorbate) after the bleaching procedure [44]. Delayed bonding (up to 7 days) was also found by two studies to increase the shear bonding strength of ceramic to enamel [40,44].

Table 3. Main findings of studies on bond strength of ceramic/metal to enamel after bleaching protocol.

Author	Specimen	Bleaching Materials	Intervention	Testing Method	Restorative Material	Qualitative Analysis	Summary of Results
Rahul et al., 2017 [35]	Human lower premolars teeth ($n = 96$)	Opalescence Boost PF gel (40% hydrogen peroxide) (Ultradent, South Jordan, UT, USA) (at-home) and Opalescence non-PF (10% carbamide peroxide) (Ultradent, South Jordan, UT, USA) (in-office)	Group 1 ($n = 30$): at-home bleach was applied for 8 h daily for 14 days. Group 2 ($n = 30$): in-office bleaching gel was applied for 20 min and then washed away, with repeated procedure the next day. Between intervals and after completion of bleaching protocol, all specimens were stored in distilled water. Control ($n = 30$)—no treatment $n = 6$ specimen used for SEM	SBS	Metal, ceramic, and composite bracket	Yes	No significant change in shear bond strength was found in at-home testing groups against all restorative materials after 24 h (14.68 ± 1.67 MPa). Significant decrease was observed in-office groups against all tested materials (10.95 ± 2.61 MPa), while shear bond strength of ceramic brackets in the control group was 16.03 ± 0.87 MPa.
Cooper et al., 2016 [41]	Bovine teeth ($n = 40$)	10% carbamide peroxide gel (OpalescenceVR, Ultradent Products, Inc., South Jordan, UT, USA)	Flattened and polished specimens were used. ($n = 10$)—unbleached (control) ($n = 10$) bleached with 10% Opalescence for 10 s ($n = 10$) bleached with 10% Opalescence for 20 s ($n = 10$) bleached with 10% Opalescence for 30 s	SBS	Resin veneering cement	No	No significant difference in bond strength was found after bleaching for 10 s (16.1± 3.7 MPa), 20 s (15.0 ± 2.8 MPa), or 30 s (15.2 ± 2.1 MPa) and control (15.9 ± 3.7 MPa) groups.
Britto et al., 2015 [40]	Bovine teeth ($n = 100$)	35% hydrogen peroxide agent (Whiteness HP Maxx 35%, FGM, Joinville, Santa Catarina, Brazil)	Group 1 ($n = 20$): no bleaching (control) Group 2 ($n = 20$): bleached for 3 × 15 min. Group 3 ($n = 20$): bleaching protocol same as group 2, prior to specimens being washed and dried followed by application of desensitising agent. Group 4 ($n = 20$): bleached for 40 min, then specimens were washed and dried, followed by polishing with a felt disc. Group 5 ($n = 20$): bleached for 40 min, then specimens were washed and dried, followed by application of desensitising agent for 10 min, before being washed and polished with a felt disc. Bonding was done after 7 days.	SBS	Orthodontic ceramic bracket	No	Shear bond strength: Group 1 control: 19.19 ± 6.12 MPa, Group 2 HP Maxx 20.59 ± 7.17 MPa, Group 3 (HP Maxx + KF 2%) 24.33 ± 5.45 MPa, Group 4 (HP blue) 23.25 ± 6.85 MPa, Group 5 (HP blue + KF a 2%) 29.33 ± 6.03 MPa. Groups 2 and 5, with application of desensitising agent, increased the shear bond strength. No significant impact was observed in the shear strength bond in other groups.
Dastijerdi et al., 2015 [43]	Human premolars teeth ($n = 48$)	20% and 45% of carbamide peroxide gel (Opalescence; Ultradent Products, South Jordan, UT, USA) 40% aqueous hydrogen peroxide gel (Opalescence; Ultradent Products, South Jordan, UT, USA)	Each group had $n = 12$ specimens. Group 1: the group was stored artificial saliva and etched with 37% phosphoric acid, then steamed and dried. Group 2: 45% carbamide peroxide applied for 30 min, then rinsed, dried, and stored in artificial saliva for 2 weeks. Group 3: 20% carbamide peroxide applied for two weeks for 4 h daily. Other steps were repeated, as in Group 1. Group 4: A 40% aqueous hydrogen peroxide gel was applied for 60 s at an 810 nm wavelength. Specimens were maintained in artificial saliva for two weeks before going through the same protocols as Group 1. The metallic brackets were then bonded to enamel surfaces, which were subsequently thermocycled for 500 cycles between 5 and 55 °C.	SBS	Metallic bracket	No	Groups 2 (6.37 ± 0.92 MPa), 3 (7.67 ± 1.01 MPa) and 4 (7.49 ± 1.19 MPa) had statistically significant lower bond shear strength in comparison to Group 1 (10.54 ± 1.51 MPa), $p < 0.001$. Group 4 had no statistically significant difference between Groups 2 and 3.
Firoozmand et al., 2013 [38]	Bovine incisors teeth ($n = 144$)	35% hydrogen peroxide whiteness HP Maxx gel (FGM, Joinvile, Brazil)	Control group ($n = 72$)—none of the specimens were stored in artificial saliva at 37 °C for 14 days. Treated group ($n = 72$)—bleached for 15 min, then enamel surface rinsed with water and procedure repeated three times (45 min of bleaching in total). Specimens were stored in artificial saliva at 37 °C for one week before repeating the bleaching protocol and re-stored in artificial saliva for 14 days before bonding. Both groups were divided into two groups each ($n = 36$) (Transbond Xt group and Filtek Z250 group), which were further divided into three groups ($n = 12$), and each group was etched for either 15, 30 or 60 s before bonding.	SBS	Polycrystalline ceramic central incisor brackets, (Orthometric Inceram, Maanshan, China)	No	Significant interaction was found between bleaching and etching times within specimens. Highest shear bond strength was found in non-bleached specimens (10.67 MPa) compared to bleached specimens (9.65 MPa). Etching time of 30 s increased bond strength among groups by 14.5% or 11.05 MPa, while 14 and 60 s had lower results, 9.8 MPa and 9.63 MPa. Highest bond strength was found in samples that were not bleached but etched for 30 s − 12.41 ± 1.07 MPa.

Table 3. *Cont.*

Author	Specimen	Bleaching Materials	Intervention	Testing Method	Restorative Material	Qualitative Analysis	Summary of Results
Öztas et al., 2011 [37]	Human first premolar teeth (*n* = 120)	20% of carbamide peroxide—bleaching—gel, CP, at-home (Opalescence, Ultradent Products, South Jordan, UT, USA)	Bleached group (*n* = 80). Not bleached group (*n* = 40). Prior to bleaching, enamel was polished with pumice (oil- and fluoride-free). Bleaching agent was applied for 6 h a day for 14 days. Bleached Group 1: (*n* = 40) was bonded 24 h after bleaching. Bleached Group 2 (*n* = 40) was bonded after 14 days of bleaching. 12 subgroups were further made (*n* = 10) and metal and ceramic brackets were bonded to each group with either self- (Unite 3 MUnitek) or light-cured (Transbond XT) composite adhesives.	SBS	Ceramics and metal bracket	Yes	No statistically significant difference in shear bond strength was found between experimental and control groups when bonding occurred within 24 h or 14 days. Group 1 ceramic brackets Self-cured adhesive resin—13.794 ± 2.157 MPa. Light-cured adhesive resin—15.367 ± 3.513 MPa. Group 2 metal brackets Self-cured adhesive resin—12.131 ± 5.422 MPa. Light-cured adhesive resin—14.735 ± 4.556 MPa.
Nilgun Ozturk et al., 2011 [36]	Human maxillary central incisors teeth (*n* = 96)	38% hydrogen peroxide in-office gel (Whiteness HP Maxx 35%, FGM, Joinville, Santa Catarina, Brazil)	Bleached group (*n* = 48) and non-bleached groups (*n* = 48). Bleaching procedure was repeated twice. Prior to attaching ceramic systems (Cerec 3 and IPS Empress2), they were divided into two groups (*n* = 12), where luting agents were applied (Variolink 2 and Rely-X). Specimens were subjected to tensile forces. After luting, specimens underwent thermocycling of 1000 cycles at 5 to 55 °C	TBS	Ceramic systems	Stereomicroscope	Non-bleached groups had significantly higher shear bond strength than bleached groups. Ceramic systems had no statistically significant difference from each other.
Gökce et al., 2008 [44]	Human molar teeth (*n* = 40)	10% carbamide peroxide bleaching gel (Opalescence, Ultradent, South Jordan, UT, USA)	Group 1 (*n* = 10): ceramic specimens bonded after bleaching. Group 2 (*n* = 10): sodium ascorbate applied after bleaching. Group 3 (*n* = 10): stored in artificial saliva for 7 days prior to bonding after bleaching. Group 4 (*n* = 10): control—not bleached but immersed in artificial saliva for 7 days prior to bonding.	SBS	Ceramics (Empress 2)	Yes	No statistically significant difference was found between delayed bond Group 3 (37.5 ± 8.3 MPa) and control Group 4 (38.8 ± 4.1 MPa). Samples with immediate bonding after bleaching in Group 1 (31.6 ± 9.3 MPa) and Group 2 (41.7 ± 1.9 MPa) demonstrated significantly higher shear bond strength.
Miles et al., 1994 [42]	Human first, second upper and lower premolars teeth (*n* = 60)	10% carbamide (urea) peroxide gel (Rembrandt Lighten, Den-Mat Products, Santa Maria, CA, USA)	Group 1 (*n* = 20): control (unbleached group) Group 2 (*n* = 20): bleached and directly bonded to the ceramics Group 3 (*n* = 20): bleached and stored in distilled water for 7 days before bonding.	TBS	Ceramics	No	Group 2 showed statistically significant lower tensile bond strength than Group 1 and Group 3. No statistically significant difference in tensile bond strength was observed between control Group 1 and Group 3.

Two studies that used 35% hydrogen peroxide bleach found that the type of adhesive influences the bond strength of ceramic to enamel post bleaching procedure [36,38]. Interestingly, both studies showed that the type of luting cement affects the bond strength of ceramics to enamel post bleaching procedure. The study by Nilgun Ozturk et al., (2011) [36] recorded the highest bond strength in specimens with the Transbond XT resin adhesive, with an etching time of 30 s compared to specimens with Rely-X veneer cement adhesive; Firoozmand et al., (2013) showed higher bond strength values in specimens with Transbond XT resin adhesive compared to the Z250 composite resin adhesive [38]. The concentration of the bleach was also found to influence the bonding strength of ceramic to enamel [35,43]. The study by Dastijerdi et al., (2015) showed significantly lower bond strengths in 45% carbamide peroxide specimens than in 20% carbamide peroxide specimens when bonding was done 24 h after bleaching [43]. Similarly, Rahul et al., (2017) also found significantly lower bond strengths in specimens bleached with 40% hydrogen peroxide compared to specimens bleached with 10% carbamide peroxide when bonding was done 24 h after a bleaching procedure [35].

3.2. Changes in Surface Roughness of Enamel Post Bleaching Protocol

A total of 10 studies carried out qualitative analysis of the surface roughness of enamel after bleaching procedures using different concentrations of hydrogen peroxide (6–35%) and other commercially available bleaching systems, such as Proxigel (10% carbamide and cabapol), White and Bright (10% carbamide peroxide), Opalescence, Vital home bleaching, Rembrandt, Nupro Gold, and also placebo agents for control (Table 4). Four studies recorded minimal or no alteration to enamel surface morphology [22,25,29]. The hydrogen peroxide/carbamide peroxide contents of the bleaching agents used by these four studies were in the range of 6–22%. Alterations in enamel surface morphology were recorded by five studies using either SEM analysis, AFM analysis or light microscopic observation [13,26,45–47] and these changes included: ridged and scored, scattered depressions of various diameters and depths, a muted texture of rounded enamel rods with depressed rod boundaries, the unclear structure of dental enamel, seen by the blurring of the striae of Retzius and a darkening of the subsurface zone of enamel, indicating mineral loss in this region; a partially etched surface with many shallow depressions and an increase in surface porosity; white precipitate that could be seen in association with the enamel surface, giving it a frosted appearance. Three studies recorded greater enamel surface changes in specimens treated with 30% or more concentrations of hydrogen peroxide solution compared to the specimen treatment with bleaching agents with lower concentrations of hydrogen peroxide [45–47].

3.3. Risk of Bias

The results of the assessment of the 18 studies are presented in Table 5. None of the studies reported a method of determining the sample size or the specimen selection principle, and none of the in vitro studies applied the mechanism of randomisation, allocation, implementation, and blinding [6–9]. All included studies had reported background and objectives, intervention and outcomes accurately. However, one study did not include an abstract [29]. Several studies did not report specific objectives ($n = 8$) [10,13,25,29,40,43,45,47], sample size ($n = 3$) [10,35,47], statistical methods [10,22,25,29] and outcome and estimation [29,47]. Only five studies included had supporting funding for their research [10,22,37,38,47]. The risk of bias assessment showed that all included studies had a low risk of bias.

Table 4. Main findings of studies on surface roughness of enamel after bleaching.

Author	Analysis	Specimen	Bleaching Material	Intervention	Outcome
Rahul et al., 2017 [35]	SEM	Human lower premolar teeth (*n* = 96)	Opalescence Boost PF in-office (40% hydrogen peroxide) (Ultradent, South Jordan, UT, USA) and Opalescence non-PF at-home (10% carbamide peroxide) (Ultradent, South Jordan, UT, USA)	Group 1 (*n* = 30): at-home gel was applied for 8 h daily for 14 days. Group 2 (*n* = 30): in-office gel was applied for 20 min and then washed away, with repeated procedure the next day. Control (*n* = 30)—no bleaching treatment. Between intervals and after completion of bleaching protocol, all specimens were stored in distilled water. *n* = 6 specimen used for SEM.	40% hydrogen peroxide samples The surface alterations were greatly significant compared to other testing groups with numerous surface deposits. Morphologic surface alterations became significantly noticeable after in-office bleaching. Present irregular depressions: craters and shallow erosions were visible. 10% carbamide peroxide samples Minor changes to enamel surface were observed, including alterations in surface smoothness.
Schemehorn et al., 2004 [25]	SEM	Admixed high-copper amalgam (Dispersalloy, Dentsply, York, PA, USA) and hybrid resin composite (Herculite, Kerr, Orange, CA, USA) (*n* = 10)	6% hydrogen peroxide (Xtra White, Unilever Oral care)	Specimens were immersed in 6% hydrogen peroxide at 37 °C for 20 min, rinsed, brushed to remove residual gel and placed back in saliva for 1 h at 37 °C. Bleaching treatment repeated after 1 h immersion in saliva and specimen later immersed overnight in saliva. 1st day—4 treatments. Next four days—6 treatments each; 28 treatments in total.	There were no visual differences at magnifications of 200× or 2000× magnifications between the control group and any other bleach gel treated groups. No significant visual effects of the 6% hydrogen peroxide gel on surface alterations were observed on the tested dental materials.
Turker & Biskin., 2003 [26]	SEM	3 bleaching products and 3 restorative materials (feldspathic porcelain, glass ionomer, microfilled composite) (*n* = 30)	Nite White (G1) (Discus Dental Inc., Beverly Hills, CA, USA), Opalescence (G2) (Ultradent Products Inc., South Jordan, Utah), Rembrandt (G3) (Den-Mat Corp, Santa Maria, CA, USA)	In total, 3 groups of *n* = 10 specimens were prepared; 2 specimens from each group were used as control. Each group was bleached with one of the three bleaching agents for 8 h per day for 30 days. Surface roughness was examined at intervals of 1 day, 2 days, 1, 2, 3, and 4 weeks (30 days).	Significant increase in surface roughness was found from using G3 gel on modified glass ionomer cement. In the first 2 weeks, surface roughness dramatically increased for all bleaching groups and each restorative material. All the modified glass ionomer specimens showed cracking areas; microfilled composite samples showed significantly increased surface porosity and cracking in comparison to control specimens. Surface spectral analysis results indicated a decrease in the SiO_2 content in the feldspathic porcelain and microfilled composite groups for all bleaching materials.
Leonard et al., 2001 [22]	SEM in vivo study	Human subjects (*n* = 24) (The study teeth were the four maxillary central and lateral incisors.) untreated extracted tooth- used as control	Nite White classic (Discus Dental, Inc., Culver city, CA, USA)	Participants were exposed to bleaching protocol for 8–10 h per day for 2 weeks by wearing an active whitening solution filled guard. Impressions of the study teeth were taken at baseline (after 2 weeks) and at 6 months after treatment and epoxy casts made. Casts were examined using the SEM with magnification taken at 200× times and 2000×.	After 2 weeks of treatment, no or minimal effect on the surface morphology of enamel was observed; 6 months post treatment comparisons also showed no long-term effect or minimal alterations in enamel surface morphology.

Table 4. *Cont.*

Author	Analysis	Specimen	Bleaching Material	Intervention	Outcome
Hegedus et al., 1999 [46]	Atomic force microscopy	Extracted incisors, non-carious human teeth (ten maxillary and five mandibular) (*n* = 15)	G1: Opalescence (Ultradent Product Inc., South Jordan, UT, USA), G2: Nite White (Discus Dental Inc., Los Angeles, CA, USA) G3: 30% hydrogen peroxide (Sigma Chemical Co., Ltd., USA)	Three groups of (*n* = 5) teeth were treated with either Opalescence, Nite White or 30% hydrogen peroxide solution, respectively, for 28 h (4 individual) treatments and examined 28 h after the final treatment.	On comparing the AFM images of untreated and treated enamel. G1: - Significant difference in comparison to untreated surface was observed - Prominent grooves ranged between 30–120 nm in depth and width between 100–750 nm. - Significant irregularities were present at both sides of the base and grooves; it was noted as significantly more irregular than the pre-treatment grooves. G2 - The surface grooves were significantly prominent - The morphology of the tested specimen enamel post treatment was much more irregular - Irregularities in the depth of the grooves ranged between 20–80 nm and in the width of the grooves between 100–300 nm. - Significantly lower impact from the bleaching was observed in G2 in comparison to G1. G3 - Enamel surfaces were relatively smooth in comparison to G1 and G2; however, one of the grooves was significantly deeper, ranging between 90–350 nm, with a width between 1.0 to 1.5 µm; sides of this groove appeared rough.
Josey et al., 1996 [13]	SEM	Non-carious human teeth (*n* = 32)	Rembrandt lighten (carbamide peroxide) (Den-Mat Corporation, Santa Maria, CA, USA)	(*n* = 8)—bleached and stored in artificial saliva for 24 h. (*n* = 8) bleached and stored in artificial saliva for 12 weeks. (*n* = 8) not bleached and stored in artificial saliva for 12 weeks. (*n* = 8) not bleached and stored in artificial saliva for 24 h.	Macroscopic observation - No change in enamel surface topography was observed. Light microscopy observation Sections of specimens that underwent bleaching and were stored for 24 h or 12 weeks in artificial saliva showed demineralisation in the tested region and exhibited an indistinct structure of the enamel. SEM observation - Tested surfaces showed clear alterations in the surface texture of bleached specimens compared with unbleached specimens. - Tested specimens had partially etched surfaces with numerous shallow depressions that significantly increased surface porosity. The storage intervals did not show any significant differences between specimens.

Table 4. *Cont.*

Author	Analysis	Specimen	Bleaching Material	Intervention	Outcome
McGuckin et al. 1992 [45]	SEM	Extracted intact human teeth (n = 14)	G1: Superoxol, 30% hydrogen peroxide (Union Broach, York, PA, USA), G2: Proxigel—10% carbamide peroxide and Carbapol, (Reed & Carn-rick, Piscataway, NJ, USA), G3: White & Brite—10% carbamide peroxide (Omni Products Inter-National, Gravette, AR, USA)	Home 1 group (Proxigel bleach) (n = 4) Treatment time was 8 h per day for 30 days. Specimen rinsed in tap water every day before storage while waiting for next treatment. Home 2 group (White & Brite) (n = 4) Treatment time was 24 h daily. After exposure every day, specimens were rinsed in tap water for 30 s, then placed in 4% fluoride gel, and re-rinsed in tap water prior to being exposed to bleaching protocol again. Office bleaching group (30% hydrogen peroxide) (n = 4) Treatment time was 30 min, repeated after 7 days. After exposure, specimens were rinsed in tap water prior to storage in isotonic saline with 0.2% sodium azide until next treatment. Control (n = 2) no bleaching treatment specimen stored in isotonic saline with 0.2% sodium azide	Mean surface roughness control (1.9 µm), Proxigel (1.06 µm), White & Brite (0.9 µm), office (0.6 µm). SEM analysis Control - Enamel surface appeared rigid, with evident scattered depressions. - Office (30% hydrogen peroxide) - Labioincisal surface—muted texture with rounded enamel rods and depressed rod borders. - Faciogingival surface—smoother than the incisal surface, with random voids in the enamel that were not present in the incisal region. - Gingivofacial surface—topographic characteristics appeared to have been eliminated. The enamel was badly scratched, and the scratches were in a random pattern. Home 1 (Proxigel) - Irregular depressions of different diameters and depths on specimens. Intermittent located and oriented scratches, scattered debris was present on the surface, fewer particles were visible than in the control group. Home 2-White and bright - Present deposit of evenly distributed small particles across the entire surface (approximately 0.5 to 1.0 pm in size). Particles were smaller, but deposits were denser than the control group. - Surface topography displayed random oriented scratches and depressions of various sizes.
Titley et al., 1991 [10]	SEM	Bovine teeth (n = 128)	35% hydrogen peroxide (Drug Trading Co. Ltd., Toronto, ON, Canada)	Group 1: specimens were immersed in 35% hydrogen peroxide for 5 or 30 min, washed with tap water for 1 min, dried with air, then etched with 37% phosphoric acid, washed, and dried again. Group 2: bleaching protocol same as Group 1, but specimens were immersed in saline instead of hydrogen peroxide. Group 3: was treated with E for 60 s, washed before immersion in hydrogen peroxide, then rinsed, etched, washed and dried again. Group 4: was treated the same as Group 3, except it was immersed in saline.	It was suggested that there could be an interaction between the resin and the residual hydrogen peroxide at or near the enamel surface.

Table 4. *Cont.*

Author	Analysis	Specimen	Bleaching Material	Intervention	Outcome
Scherer et al., 1991 [29]	SEM	Extracted non-carious human anterior teeth in 10% buffered formalin solution. (*n* = 15)	Vital home bleaching (10%) (manufacturer not stated)	Specimens were divided into five groups: Control (*n* = 3)—no treatment Vital bleach Group 1 (*n* = 3), bleached for 5 days Vital bleach Group 2 (*n* = 3) bleached for 15 days. Vital bleach Group 3 (*n* = 3) bleached for 30 days. Etched group (*n* = 3)—specimen etched with 37% phosphoric acid gel for 20 s.	Photomicrographs showed that the etching pattern on enamel surfaces was exhibited and visible only in specimens that were treated for 30 days. SEM analysis showed no significant morphological differences among the 5-day, 15-day, and 30-day treatment specimen groups.
Titley et al., 1988 [47]	SEM	Paired human tooth sections (*n* = 36 sections)	35% hydrogen peroxide (Drug Trading Co. Ltd., Toronto, ON, Canada)	Group 1—bleached with 35% hydrogen peroxide or normal saline. Group 2—bleached with 35% hydrogen peroxide for durations of 1,3, 5, 10, 20, 30, and 60 min prior to 60 s etching with 37% phosphoric acid. Control—stored in normal saline for durations of 1, 3, 5, 10, 20, 30, and 60 min prior to etching with 37% phosphoric acid for 60 s. Group 3—60 s etching with 37% phosphoric acid prior to being kept in 35% hydrogen peroxide for durations of 1,3, 5, 10, 20, 30, and 60 min. Control—60 s etching with 37% phosphoric acid prior to being kept in normal saline for durations of 1,3, 5, 10, 20, 30, and 60 min.	Hydrogen peroxide immersion only - The removal of dust and debris particles from the specimen was enabled with extended immersion. - White precipitate on the enamel surface was noticed after 60 min of storage that was more visible in areas with altered enamel surfaces only. Hydrogen peroxide immersion + etching - More white precipitate appeared on the etched surfaces after 20 min storage in the hydrogen peroxide group than in the control group. - A considerable rise in both the white precipitate and the porosity of the enamel surface was detected after 30 min storage in hydrogen peroxide. - The precipitate became so dense that the bleached enamel surface shape was obliterated after 60 min storage in hydrogen peroxide Surface etching, followed by immersion in hydrogen peroxide. - The specimen kept for 10 min showed an increase in porosity. - The specimen stored for 60 min appeared highly permeable.

Table 5. Risk of Bias.

		Rahul et al., 2017 [35]	**Cooper et al., 2016** [41]	**Britto et al., 2015** [40]	**Dastjerdi et al., 2015** [43]	**Firoozmand et al., 2013** [38]	**Nilgun Ozturk et al., 2011** [36]	**Öztas et al., 2011** [37]	**Gökce et al., 2008** [44]	**Schemehorn et al., 2004** [25]	**Turker & Biskin, 2003** [26]	**Leonard et al., 2001** [22]	**Hegedus et al., 1999** [46]	**Titley et al., 1988** [47]	**Josey et al., 1996** [13]	**Miles et al., 1994** [42]	**McGuckin et al., 1992** [45]	**Titley et al., 1991** [10]	**Scherer et al., 1991** [29]
Abstract	Abstract 1 [1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Introduction	Background and objectives 2 a [2]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Specific objectives 2 b [2]	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	No	No	No
Method	Intervention 3	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Outcome 4	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Sample size 5	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes
	Randomisation: sequence generation 6 [3]	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Allocation concealment mechanism 7 [3]	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Implementation 8 [3]	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Blinding 9 [3]	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Statistical methods 10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No
Results	Outcome and estimation 11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Discussion	Limitations 12	Yes	Yes	No	No	Yes	No	No	Yes	No	Yes	No	No	No	No	No	No	No	No
Other Information	Funding 13 [4]	No	No	No	No	Yes	No	Yes	No	No	No	Yes	No	Yes	No	No	No	Yes	No
	Trial protocol 14 [4]	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Risk of bias	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

[1] Abstract of the study design, methods, results, and conclusions. [2] Introduction section that includes background and objectives/hypothesis. [3] Results that include random allocation sequences that include the steps taken for them. Sources of funding and the support presence of a trial protocol that can be accessed. [4] Sections that include sources of external support and funding and if there is a available trial protocol as external source.

4. Discussion

This systematic review has aimed to appraise the current literature on the bond strength of ceramic to bleached enamel and changes in the surface roughness of enamel post bleaching protocol. Ceramic restorations and tooth bleaching have become popular treatment options in response to modern aesthetic demands in dentistry. The bleaching protocol involves the penetration of hydrogen peroxide or carbamide peroxide molecules into the tooth structure and the subsequent oxidisation of the stain molecules [2]. Residual oxygen released during the bleaching process prevents resin penetration into the etched enamel and, therefore, reduces resin polymerisation, decreasing bond strength [10].

Two studies analysed the different methods of bleaching on bond strength between enamel and ceramic and found that bonding strength is influenced by the concentration of bleaching agents [35,43]. One study compared the bonding strength of specimens bleached with 45% carbamide peroxide with specimens bleached with 20% carbamide peroxide [43], while the other study [35] compared specimens bleached with 40% hydrogen peroxide with specimens bleached with 10% carbamide peroxide. Both studies found that specimens that were subjected to bleaching protocols containing a higher concentration of carbamide peroxide and hydrogen peroxide had significantly lower bonding strength. Three other studies that used 10–20% carbamide peroxide bleaching agents [37,41,42] did not report any statistically significant difference in bonding strength. One of the most commonly used active bleaching agents is hydrogen peroxide, and with the use of higher concentrations, there is the potential increase in hydrogen peroxide to create oxygen-free radicals that interact with coloured organic molecules and oxidise pigment stains and macromolecules, which change dental discolouration into smaller and lighter molecules [33,35]. Subsequently, more residual oxygen will be present on the etched enamel surface; this will interfere with the resin infiltration into the enamel structure and also the polymerisation of the resin.

A few studies found that in addition to delayed bonding (up to 7 days), applications of 10% sodium ascorbate (antioxidant) [44] and desensitising agents [40] after the bleaching treatment increased the bond strength between ceramic and enamel. The authors further stated that a possible reason for an increase in bonding strength in delayed bonding situations may be that the residual oxygen gets neutralised over time and, thus, does not interfere with the polymerisation of resin composites for bonding. Another study indicated that the enamel surface immediately after in-office or home bleaching is unsuitable for the adhesion of restorative materials, and it is essential to allow adequate time after bleaching to ensure the normal penetration of adhesives onto the enamel surface [36].

Two studies found higher bond strength in specimens with an application of either desensitising agent or antioxidant after bleaching compared to that of unbleached specimens [40,44]. The sodium ascorbate antioxidant has been stated to facilitate the free-radical polymerisation of adhesive resins without early cessation by re-establishing the altered redox potential of the oxidised bonding substrate and subsequently reversing the compromised bonding effect [44]. The use of desensitising agents directly after bleaching with hydrogen peroxide could be considered an alternative procedure to decrease undesired consequences of residual oxygen on bond strength. However, it is recommended to conduct further studies on the chemical and mechanical effects of bleaching gels containing calcium and desensitising agents that are applied to dental structures [40].

The concentration of hydrogen peroxide/carbamide peroxide has also been shown to influence the surface alteration of enamel. Studies recorded greater enamel surface changes in specimens treated with a 30% or higher concentration of hydrogen peroxide solution than specimen treatments with bleaching agents with lower concentrations (range of 6–22%) of hydrogen peroxide [45–47]. The study by Hegedüs et al., (1999) examined the effect of bleaching agents (Opalescence, Nite White, 30% hydrogen peroxide solution) on the enamel surface with atomic force microscopy and found that the depth of grooves present on the enamel surface post bleaching is directly proportional to the concentration of hydrogen peroxide [46]. The authors suggested that peroxide affects the inner structure and organic phase of enamel. The reaction between peroxide and the organic materials on either the surface or subsurface enamel causes alterations in the enamel surface structure [47].

The efficacy of any bleaching procedure depends on the concentration of bleaching agents and bleaching time [1]. The current literature indicates that both at-home and in-office bleaching can affect the surface roughness of enamel and, thus, the shear bond strength between ceramic and enamel [48–50]. Therefore, clinicians need to understand the effect of bleaching treatments on enamel and follow protocols shown by studies to improve the bonding strength between ceramic and enamel to increase the clinical success rate in aesthetic dentistry.

5. Conclusions

The findings of this systematic review have drawn the following conclusions:

1. Bleaching treatments alter the surface roughness of enamel and, thus, the shear bond strength between ceramic and enamel.
2. Bleaching treatments with a higher concentration of hydrogen peroxide (more than 35%) reduce the bond strength between ceramic and enamel.
3. Delaying bonding after bleaching for up to 7 days increases the bond strength between ceramic and enamel.

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