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"Effectiveness of Antoxidant Treatments in Restoring Composite Bond Strength after Tooth Bleaching: An In Vitro Comparative Study "

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ABSTRACT

Background: Tooth-whitening using hydrogen peroxide weakens the strength of resin-enamel bonds because of the residual free radical oxygen that prevents polymerisation of the acid bond. Use of antioxidants could help address the effects to a large extent through the elimination of the radical species, resulting in the recovery of bonding.

Objective: To compare the effectiveness of Proanthocyanidin (PA) a in restoring composite bond strength to bleached enamel.

Methods: This in-vitro study considered 84 upper incisors divided into four groups that included a control, a bleached control, bleached-potassium aluminium phosphate (PA) mix, and. Antioxidants were done after bleaching with 35 per cent hydrogen peroxide. Shear bond strength (SBS) was evaluated by a universal testing machine and the failure modes were analysed by scanning electron microscopy (SEM).

Results: Antioxidants improved SBS significantly ($p<0.05$), with PA restoring values close to unbleached enamel. SEM revealed more cohesive failures in PA-treated specimens, indicating stronger adhesion.

Conclusion: Application of an antioxidant immediately after tooth bleaching prevents the reduction in bond strength that is commonly encountered. In this context, the proanthocyanidin has displayed greater efficacy

Keywords: *Tooth bleaching, Proanthocyanidin, Shear bond strength, Antioxidants.*

1. INTRODUCTION

Discolouration of teeth, be it extrinsic or intrinsic, has emerged to be the main issue in the field of aesthetic dentistry, thus leading to an outbreak of bleaching services in patients who wish to have a whiter smile [1]. Hydrogen peroxide (H_2O_2) is used extensively in in-office bleaching to penetrate enamel and degrade the pigmented molecules due to reactive oxygen species (ROS), thus achieving substantial whitening [2]. Nevertheless, this oxidative action does not remove all residual oxygen in the enamel substrates, and this vitiates polymerisation of resin-based bonding agents, producing poor bond-strength of later composite restorations [3, 4, 5]. Weakened adhesion interfaces can translate into loss of immediate strength in restoration after bleaching, enhanced microleakage and shorter life of bonded restorations clinically. In this way, it is pivotal to comprehend the adverse outcome of H_2O_2 bleaching on bonding so as to guarantee the success of restorative procedures both in terms of functionality and aesthetics. The changing social perceptions are also seen in this rising demand for tooth whitening, as a brighter smile is perceived as a youthful, confident, and professional one. Nonetheless, chemical operation influences the morphology and the composition of the enamel surface, which causes doubts regarding the durability of restorative materials used after bleaching.

Conventionally, to overcome impaired bond strength, clinicians have postponed restorative procedures up to 24 hours to 4 weeks, which allows the natural outflow of remaining oxidants [1, 2, 5, 6] .Although this delay was effective, it is not viable for patients who may want to receive treatment soon. The alternative methods, most commonly in a form of adhesives with organic solvents (e.g. ethanol or acetone), have provided a partial benefit by pushing the remaining oxygen out of the way, but are rarely able to bring the bond strength back to close to starting levels [3, 7]. Such ways generate unstable results and fail to surmount the immediacy of the modern dental practice.

The property of ROS to oxidise the bond and depolymerise the resin can be reversed through the use of antioxidants, especially those of plant origin, such as Proanthocyanidin (PA) which is a lipid-soluble. PA also facilitates cross-linking of collagen, and this may increase the integrity of the adhesive [1]..

2. MATERIALS AND METHODS

Sample Selection and Grouping

A total of 84 extracted, caries-free human maxillary incisors were used. Teeth were cleaned, stored in 0.1% thymol, and embedded in acrylic blocks exposing the labial enamel surface. Samples were randomly allocated into four equal groups (n=28).(Table 1)

Group	Treatment
I	Control – no bleaching, no antioxidant
II	Bleaching only – 35% H_2O_2, no antioxidant
III	Bleached + 6.5% Proanthocyanidin (PA)

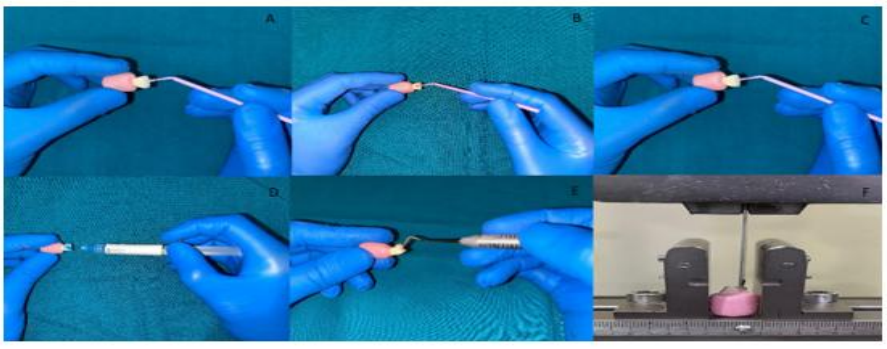
Table 1: Sample Grouping

Bleaching procedure was conducted by applying a 35% hydrogen peroxide gel across the labial surfaces of the enamel of the specimens included within Groups II, III. Their exposure time to the enamel was taken to be 30 minutes in the phase of simulating in-office bleaching. Any remaining gel was washed with distilled water for 60 s after the bleaching period and air-dried very carefully, so that no remnant peroxide was available on the surface. This was an important step since free oxygen radicals, even after resin adhesive sealing, were known to inhibit polymerisation of resin adhesives within the enamel.

Groups III and IV were treated with an antioxidant immediately after bleaching in order to eliminate the oxidative stress created by hydrogen peroxide. In Group III, a new concentration of 6.5% Proanthocyanidin in solution was added and left for 10 minutes. Grape seed extract powder was used as a source of proanthocyanidin, which was dissolved in deionised water and diluted to an adequate concentration, and finally, using a micro brush, the solution was applied uniformly on the test sample. Application of the antioxidant in the same manner was effected in 10 minutes.

Once the antioxidant treatment had been performed, the specimens were rinsed with distilled and

dry air effectively.



(A)Application of bleaching agent ,(B) Application of Proanthocyanidin (C)Application of bonding agent (D) Composite buildup on labial surface (E) Universal testing machine

Before any experiments were performed, all study groups underwent the same bonding regime. Surface etching of 37% phosphoric acid (etchant) for 15 s was done and then rinsed 20 s, and dried. A bonding agent on the market was used as directed by the producer (Figure 1). The composite resin was then applied in small yet progressive portions until the preferred standardised shape was attained, which was the cylindrical specimens measuring 4-mm in diameter and 2 mm in height. This was then light-cured using an LED unit. The samples then were put in distilled water at 37 °C and left to incubate for over 24h to simulate an intraoral environment after which shear bond strength was determined.(Table 2)

Step	Details
Bleaching Agent	35% Hydrogen Peroxide gel applied for 30 minutes.
Rinsing Post-Bleaching	Distilled water rinse for 60 seconds followed by gentle air drying.
Proanthocyanidin (Group III)	6.5% solution prepared by dissolving grape seed extract in distilled water; applied for 10 minutes.
Post-Antioxidant Rinsing	Distilled water rinse for 60 seconds and air drying before bonding procedures.

Table 2: Experiment Process

Testing and Analysis

In accordance with the standard procedures, specimens were tested in the universal testing machine at a crosshead speed of 1mm/min to obtain SBS in Megapascals (MPa). Fracture surfaces were gold-coated and examined under SEM. Failure patterns were classified:

Adhesive: at resin–enamel interface

Cohesive: within enamel or composite

Mixed: combination of both types

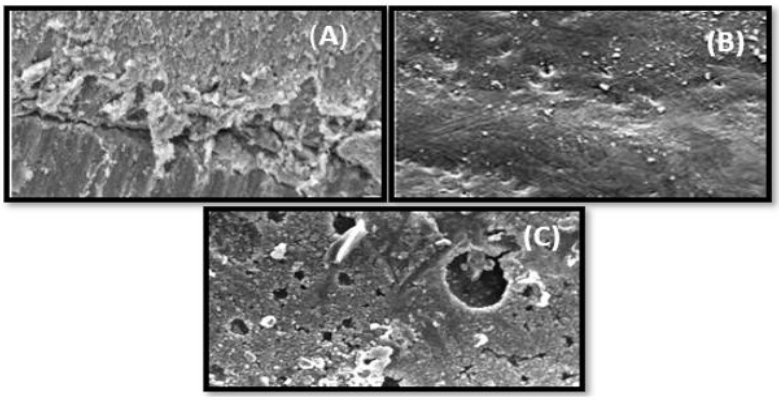
The presence of a normal distribution of SBS data was established. Comparison of groups was performed through one-way ANOVA, whereas post-hoc comparisons were performed using Tukey HSD. Chi-square test (alpha 0.05) was used in evaluating the frequencies of failure modes.

3. RESULTS

The mean shear bond strength (SBS) was measured for four experimental groups using a universal testing machine. The control group (unbleached, Group I) achieved the highest SBS value of 23.43 MPa (SD 1.58), reflecting the strongest resin–enamel interface. In contrast, Group II (bleached with 35% carbamide peroxide, no antioxidant) recorded the lowest mean SBS at 14.26 MPa (SD 1.46), indicating that residual oxygen from bleaching inhibited resin polymerization and weakened bonding.

Group III, bleached and treated with proanthocyanidin, reached a mean SBS of 22.61 MPa (SD 1.22), nearly restoring bond strength to control levels. One-way ANOVA confirmed statistically significant differences between groups ($F = 23.56$, $p < 0.001$). Post-hoc analysis showed that both antioxidant-treated groups differed significantly from the bleached-only group, with proanthocyanidin outperforming alpha-tocopherol ($p = 0.03$)

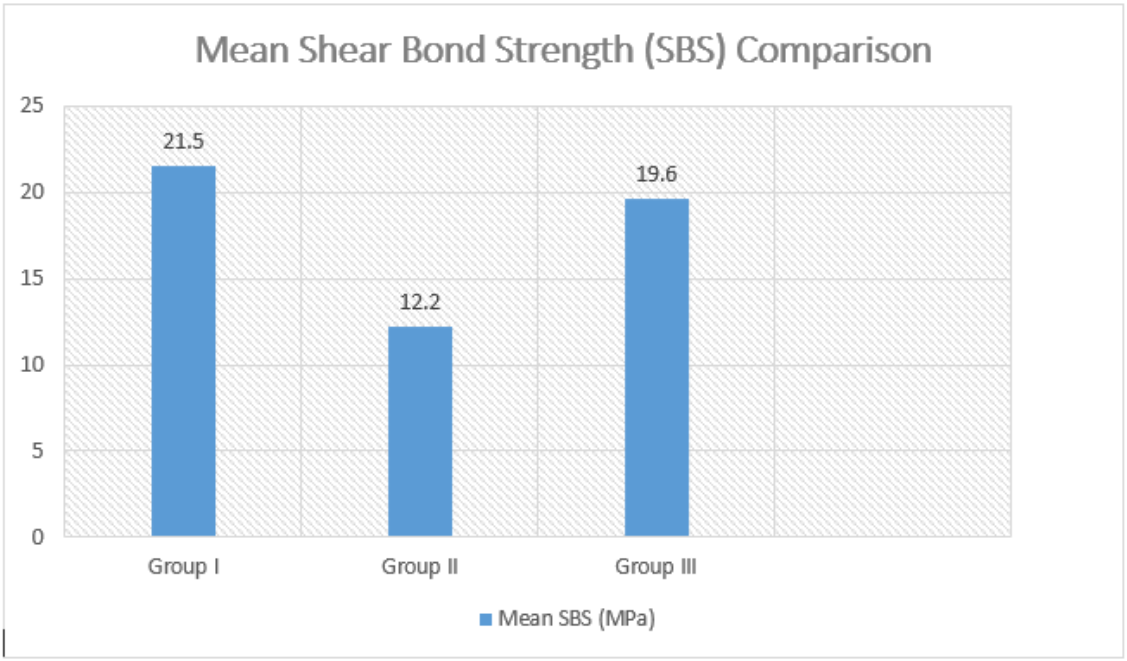
Scanning electron microscopy (SEM) revealed distinct failure modes



(A) Group 1, (B) Group 2 , (C) Group 3

(fig.2). Group I mainly showed cohesive and mixed failures, indicating strong bonding. Group II exhibited predominantly adhesive failures, consistent with its reduced SBS and compromised interface. Group III showed mostly mixed and cohesive failures, closely resembling the control pattern, supporting the effectiveness of proanthocyanidin in restoring mechanical integrity.

Chi-square analysis ($\chi^2 = 15.72$, $p = 0.028$) confirmed a significant relationship between treatment type and failure mode. Overall, both antioxidants improved SBS compared to bleaching alone, but proanthocyanidin demonstrated superior recovery, bringing values close to unbleached enamel. SEM images further supported these findings, showing stronger and more stable adhesion in proanthocyanidin-treated specimens.



Graph 1 : Mean Shear Bond Strength (SBS)

4. DISCUSSION

The current study shows that proanthocyanidin (PA) reduce the loss in shear bond strength (SBS) induced by hydrogen peroxide bleaching. Retention of remainder oxygen radicals in bleached enamel prevents ordinary free-radical resin monomers from polymerising, hence the bond strength is 25-60 per cent off the baseline in vitro tests [1, 4, 7, 8, 9]. The use of the antioxidant returns these degraded bonds to a stable state by neutralising the unbound radicals, and standard ageing kinetics can be observed once again.

PA performed significantly better among the two agents tested. PA is a flavonoid of plant origin which scavenges the oxygen radicals at the same time as enhancing collagen cross-linking to the adhesive interface, thus strengthening it. There was a tremendous amount of data that showed that PA had both the effect of restoring SBS to values that are not statistically different to unbleached enamel and the grouping of cohesive failure modes that is evidence of stronger enamel-resin bonding.

PA has the two-sided ability to neutralise any remaining oxidants with biochemical strengthening of the collagen matrix.

The current research confirms the outcome of the research study done by Nishad et al. (2018) who showed that 5% PA solution vastly reversed post-bleaching bond strength in human dentin compared to that recorded using 30% AT, which we also recorded when we found out that the use of the PA was highly effective [4]. Further, there is a voluminous literature base underlying the applicative use of sodium ascorbate to curb impaired bonding, an amount of up to 10% thus fulfilling the notion that water-soluble antioxidants are magnificent in countering free radicals [10, 12, 13, 14, 15] .However, sodium ascorbate does not have the same collagen-enhancing effects that PA has and as such is not as useful in strengthening enamel after bleaching. Recent comparative studies with a different range of antioxidants, e.g., the grape seed and pine bark extract, reveal that the agents containing PA are more effective than other antioxidants in SBS recovery [6, 8, 16]. Globally, both the current and the previous research support the common front that PA is one of the best antioxidants as far as immediate bonding is concerned, after bleaching.

The current results are clinically important. Traditionally, clinicians have chosen to wait 1 to 3 weeks after bleaching to perform adhesive procedures in order to counter the loss of bonding strength- a route inconvenient to both clinicians and patients [13]. Alternatively, the performance of bonds can be restored by activated peroxide (PA) cream/solution immediately, without the need to wait a long time after a delay period to remove the residual oxygen. This will allow us to perform composite restorations on the same day, which will improve efficiency since the treatment can satisfy patients more.

The current in vitro study, although adequately controlled, does not reflect complex conditions of the oral environment, especially salivary flow, thermal change, mechanical loading and enzymatic action. Besides, the long-term stability of the adhesive systems, along with the masticatory forces, was not tested. Further validations, preferably using living and dead clinical trials, should be considered then to evaluate the long-lasting performance and stability of antioxidant-enhanced bonding procedures, especially to the polyacrylate-based agents. It may also be possible to determine optimal levels, exposure times and routes of administration (e.g. gel or varnish) of polyacrylates and combinations of these agents with synergistic antioxidants. Lastly, patient safety, cost effectiveness and patient satisfaction studies will be essential in the diffusion of these findings to standard clinical practice. A previous comparative study revealed that multiple antioxidant agents restore adhesion with differing effectiveness . Such findings highlight the need for further evaluation of antioxidant strategies[17].

5. CONCLUSION

This in vitro study tests the ability of immediately applied antioxidants to regain the lost resin enamel bond strength due to the application of 35% hydrogen peroxide. Proanthocyanidin (PA) displayed considerable gains in shear bond strength compared to bleached samples. PA performed better: it was able to reverse bond strength close to unbleached baseline values and among its main failure modes were cohesive and mixed under scanning electron microscopy. It is probably caused by the unique dual action of PA as a strong free radical scavenger and collagen cross-linker, as it strengthens the bonding interface. Such outcomes contribute to the assembling clinical implication of PA as a potential alternative to immediately replacing composite after bleaching.

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