

## Research Article



# Adhesive systems applied to dentin substrate under electric current: systematic review

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### Conflict of Interest

No potential conflict of interest relevant to this article was reported.

### Author Contributions

Conceptualization: Vitti RP. Data curation: Maciel CM, Souto TCV, Pinto BA. Methodology: Vitti RP, Maciel CM. Project administration: Vitti RP. Resources: Souto TCV, Pinto BA. Supervision: Vitti RP. Validation: Silva-Concilio LR, Baroudi K. Writing - original draft: Maciel CM, Vitti RP, Baroudi K. Writing - review & editing: Baroudi K.

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## ABSTRACT

**Objectives:** The purpose of this systematic review was to collect and discuss the technique of adhesive systems application on dentin substrate under electric current.

**Materials and Methods:** The first search strategy was based on data available at PubMed, LILACS, Scielo, Scopus, and Cochrane Library, using a combination of descriptors such as “dentin bond agents OR adhesive system AND electric current OR electrobond” or “dentin bonding agents OR dentin bonding agent application OR adhesive system AND electric current OR electrobond”, with no limit regarding the publication year. The second search strategy was based on the articles' references found previously. An additional search strategy was applied that concerned the proposed theme in the SBU-UNICAMP (Unicamp's Library System Institutional Repository).

**Results:** Twelve studies published between 2006 and 2020 were found. The analyses of the selected studies showed that the use of electric current during adhesive systems application on dentin, whether conventional or self-conditioning, increases resinous monomer infiltration in the dentin substrate, which improves the hybridization processes and the bond strength of the restorative material to dentin.

**Conclusions:** Despite the favorable results related to the use of this technique, there is still no specific protocol for the application of adhesive systems under electric current.

**Keywords:** Dentin adhesives; Dentin substrate; Bond strength; Electric current

## INTRODUCTION

The failures in the tooth-restoration adhesive interface may occur due to errors in the application of the adhesive system onto the dentin, wear or fractures of the restoration [1]. Errors in adhesive restorative procedures may also occur due to chemical degradation of the adhesive interface. This occurs mainly due to the presence of demineralized collagen fibers that are not totally infiltrated by resinous monomers. These collagen fibers suffer the action of proteolytic enzymes (matrix metalloproteinase; MMP) present in the dentin substrate itself [2].

To improve resinous monomer infiltration to the dentin and, at the same time, reducing the water sorption rate and the collagen fibril degradation, some clinical protocols were

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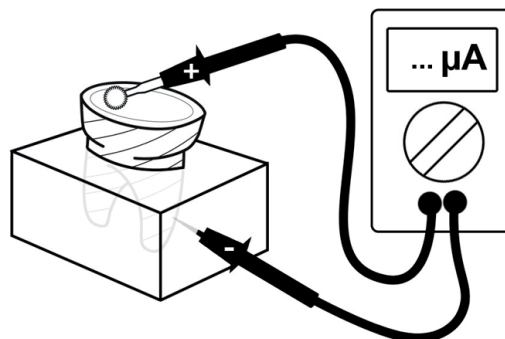
proposed [2-11]. However, all of them increased the number of clinical steps, which exposes the restorative technique to errors, apart from increasing the duration of the clinical procedure. To improve the dentin substrate monomer infiltration without increasing the number of clinical steps, the application of adhesive systems with an electric current transmission device was developed [12].

The device works with a method called iontophoresis, in which the device induces electrons through the dentin tissue. The dentin surface, negatively-loaded (anode), repels negatively-loaded chemical substances, whereas the adhesive application device, positively-loaded (cathode), repels positively-loaded chemical substances into the dentin substrate (**Figure 1**) [13,14]. Therefore, through a flow of electrons, the electric current activates the polar monomers that are present in dentin surface adhesive systems [3,14,15]. Furthermore, apart from the direct electrostatic effect on the polar monomers present in the adhesives, the technique helps in the water evaporation and solvent penetration, apart from modifying the dentin matrix wettability and decreasing the contact angle formed between the adhesive and the dentin [3,16].

However, this method is a technique that is little known and studied in dentistry. Therefore, for better comprehension of this methodology, this systematic review aimed at collecting data to discuss publications that feature the application of such technique and analyzing the studied adhesive materials as well as describing the applied protocol and its results on the bond strength and the hybrid layer formation.

## MATERIALS AND METHODS

This systematic review was carried out according to the criteria established by Cochrane [17]. The applied methods included the search of scientific studies related to the use of the electric current in the application of adhesive systems onto the dentin. The first search strategy was based on data available at PubMed, LILACS, Scielo, Scopus, and Cochrane Library, using a combination of descriptors such as “(dentin bond agents) OR (adhesive system) AND (electric current) OR (electrobond)” or “(dentin bonding agents) OR (dentin bonding agent application) OR (adhesive system) AND (electric current) OR (electrobond)”, with no limit regarding the year of publication. The second search strategy was based on the references of the papers found with the first search. Lastly, an additional search strategy was applied in the search for scientific



**Figure 1.** Schematic illustration of the adhesive systems applied on dentin using electric current. Tooth placed on moist sponge and application of adhesive system under electric current using the positively-loaded tip (+: cathode). The negatively-loaded tip (-: anode) attached on root. Display showing the electric current (...) adjusted by operator.

studies that concerned the proposed theme in the SBU-UNICAMP (Unicamp's Library System Institutional Repository), as this institution has a research group working on this theme.

The inclusion criteria applied in the search of fully-published papers and studies developed by undergraduate and graduate students (monographs, dissertations, theses), written in English or Portuguese. Studies that analyzed the effect of the electric current in the infiltration of monomers on the dentin substrate or in prototypes that simulated the dental composition. Literature review and patent-related researches were excluded from the analysis.

The search, reading, and selection of papers were carried out by 2 independent reviewers and in accordance with the search, inclusion, and exclusion criteria. The search was performed and updated up to October 28th, 2020, and a third reviewer excluded eventual disagreement between reviewers, and also discarded duplicate articles.

## RESULTS

The database with results for this research was PubMed and Medline, with 12 studies published between 2006 and 2020. The description of search strategies associated with the inclusion and exclusion criteria and their results is described in **Figure 2**.

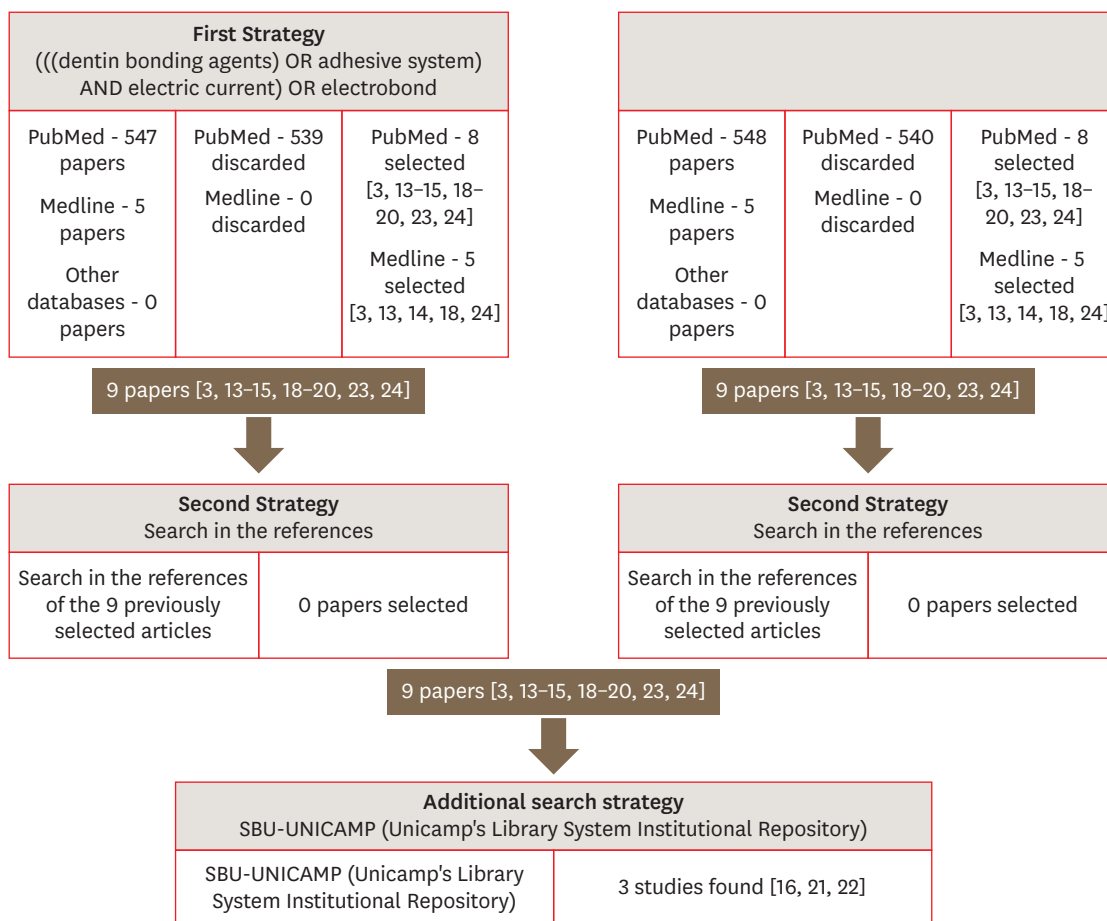


Figure 2. Chart of search and results strategies.

Some studies cite [13,15,16,18-23] or refer [14,24] the intensity of the applied electric current. One single paper concerned the application of the electricity-assisted technique to evaluate the pulp cell vitality [18]. The other works evaluated *in vitro* the human tooth-restoration bond strength submitted to mechanical trials [3,14,15,18,19,21-24], the contact angle [14,16] formed by the adhesive and the tooth and/or carried out qualitative analyses in microscopy [3,13-16,18,19,22-24], as described in **Table 1**.

**Table 1.** Papers' description (authors and year of publication, electric current intensity, resinous monomers, and applied tests/found results)

Authors	Year	Electric current intensity	Type of publication	Adhesive systems	Tests and Results	Microscopy and Results
Breschi et al. [3]	2006	Not specified	Scientific paper	1 self-etching 2-step; 2 self-etching single-step	Bond strength increase for all applied adhesives with electric current, with no statistical differences among them.	SEM. Nanoinfiltration reduction with the use of electric current, especially with 1-step adhesives.
Pasquantonio et al. [15]	2007	20 $\mu$ A	Scientific paper	3 conventional 2-step	Bond strength increase for all applied adhesives with electric current, with no statistical differences among them.	SEM. Nanoinfiltration reduction with the use of electric current.
Visintini et al. [24]	2008	20 $\mu$ A (citing another study [15])	Scientific paper	2 self-etching single-step	Bond strength increase for all applied adhesives with electric current (with thermocycling).	TEM. Nanoinfiltration reduction with the use of electric current.
Mazzoni et al. [13]	2009	50–110 $\mu$ A	Scientific paper	2 conventional 2-step	Bond strength increase for all applied adhesives with electric current, with no statistical differences among them.	TEM. Nanoinfiltration reduction with the use of electric current.
Gharizadeh et al. [20]	2010	Up to 15 $\mu$ A	Scientific paper	1 conventional 2-step	Thermocycling.	Analysis in stereomicroscope at 40X. Nanoinfiltration reduction with the use of electric current, before or after thermocycling.
Toledano et al. [14]	2011	Not specified (citing other studies [13,15,19])	Scientific paper	37%-phosphoric acid (control); 1 self-etching 2-step; 1 self-etching single-step	The electric current reduced the contact angle with acid and 2-step adhesive.	AFM. Evident intertubular roughness increase with all adhesives with the use of electric current, in ascending order: Self-etching single-step > acid > self-etching 2-step
Barcellos [21]	2012	20 and 40 $\mu$ A	Monograph	2 self-adhesive resin cements	The electric current did not influence the results on the adhesion between the indirect resin composite restoration and the dentin substrate with the use of resin cements.	-
Chen et al. [18]	2014	10, 20, 50, 60, 70, and 90 $\mu$ A	Scientific paper	1 self-etching single-step	Bond strength increase for 60, 70, and 90 $\mu$ A electric current. 20 to 70 $\mu$ A electric currents did not influence pulp cell vitality.	SEM. Nanoinfiltration proportionally reduced with the increase in the applied electric current.
Gotti et al. [19]	2014	20 and 40 $\mu$ A	Scientific paper	2 self-adhesive resin cements	The electric current did not influence the veneer adhesion results.	SEM. Failures in the adhesive interface between the dentin and the resin cement were found with both materials.
Guarda [16]	2016	35 $\mu$ A	Master thesis	1 conventional 2-step; 1 self-etching 2-step; 1 universal.	The electric current did not promote different contact angles in the different dentin substrates.	Confocal microscopy. Electric current promoted better hybrid layers.
Quiles [22]	2017	40 $\mu$ A	Master thesis	Experimental primer (MDP, MEP) mixed with calcium ions.	The electric current caused bond strength increase. The ionic interaction with the calcium and the bond was higher with the adhesive containing MDP.	SEM. There was no significant statistical difference in the monomer infiltration, and less failure occurred with the use of electric current.
Guarda et al. [23]	2020	0, 10, 15, 20, 25, 30, 35 $\mu$ A	Scientific paper	1 conventional 2-step; 1 self-etching 2-step; 1 universal.	Self-etching adhesive showed higher bond strength for all tested electrical currents. Higher bond strength values when using current of 35 $\mu$ A for both conventional and self-etching adhesive	LCM. The penetration of fluorescein into the hybrid layer was found for universal adhesive without the use of electric current.

SEM, scanning electron microscopy; TEM, transmission electron microscopy; AFM, atomic force microscopy; LCM, laser confocal microscopy.

Among the found research projects, the dissertation developed by Quiles [22] evaluated the application of electric current in the ionic interaction of the monomers 10-methacryloyloxydecyl dihydrogen phosphate (MDP) and 2-methacryloyloxy-ethyl dihydrogen phosphate (MEP) with calcium ions. Guarda, [16] in turn, evaluated the influence of the electric current in the diffusion of adhesive systems in different substrates using the contact angle test. The same was found in the study carried out by Toledano *et al.* [14] which evaluated the effect of the electric current during phosphoric acid application, with positive contact angle formation results.

The studies which performed resin composite restorations on dentin used micro-hybrid materials [3,13,15,16,18-24]. Only the researches by Barcellos [21] and Gotti *et al.* [19] evaluated the effect of the electric current on self-adhesive resin cement applied to the restored dentin substrate with veneer. The study of Gharizadeh *et al.* [20] analyzed the application of electric current in class V cavities and performed only microscopy evaluation, observing the adhesive interface degradation after thermocycling.

The metaanalysis involving the results obtained by the analyzed studies was discarded due to the lack of standardization among the applied electric currents, and also because each of the evaluated studies evaluated the electric current influence with different adhesive systems. The studies carried out by Guarda [16] and Guarda *et al.* [23] were the only ones that compared adhesive systems of 3 different classifications (conventional, self-etching, and universal). Guarda [16] only performed the electric current analysis in the contact angle formed between the adhesive and the dentin substrate (enamel and dentin), with no bond strength evaluation, while in the other study [23], analysis of the bond strength through microtensile testing and evaluation of the quality of penetration of the adhesive in the dentin substrate using electron microscopy were performed.

## DISCUSSION

The electric current is used in dentistry in endodontic apex locators [25], in initial caries lesion identification [8], in pulp vitality test [26-28] and for latency period evaluation of anesthetics [29]. However, the application of electric current for infiltration of resin monomers on dentin is a new technique and little studied. Among published studies, there is no consensus regarding which current is safe and indicated. The study carried out by Chen *et al.* [18] states that when applying the electric current on pulp cells, their vitality is only preserved if the electric current is up to 70  $\mu\text{A}$ . However, laboratory studies for dentin-restoration bond strength evaluation have used electric currents as high as 110  $\mu\text{A}$  [13]. Other authors [29] used the “pulp tester” with 80 mA of electric current intensity, with no pulp vitality loss. It is important to emphasize that the electric current applied by the “pulp tester” is pulsatile [29] whereas, in the electric current device, the resinous monomer impulse is continuous [15]. The continuous electric current, also named direct or galvanic current, is a current flow that does not vary with time and does not change polarities [30]. The pulsatile current, in contrast, presents a uni- or bi-directional flow which is, periodically, interrupted from time to time [31]. Therefore, apart from the electric current intensity, its flow is another parameter that must be considered in the analysis of the electric current influence on biological tissues.

Some authors [27,32] cited how essential it was for the current emitting device to have a constant intensity. However, for this to be viable, an electrical potential modulation is

required, which is possible by using an electronic circuit that provides a continuous and constant current, regardless of the electrical resistance and impedance of the tooth, and the adhesive system used [13]. Moreover, even if studies report the intensity of the applied electrical current, it is not guaranteed that this intensity will be evenly distributed over the dental substrate. Several factors may influence iontophoretic transport: dental substrate pH, weight, molecular size and concentration of resinous monomers and the intensity, voltage and time of electric current application [23,32]. Moreover, a tooth is not a homogeneous structure, as it has variability in the composition of minerals, water, collagen and thickness along its entire surface [32,33], which makes it difficult to standardize the electric current applied to the dental substrate. Thus, the electric current device must measure the local electrical resistance and, at the same time, standardize the electrical current emitted in the dental substrate, against the identified electrical resistance, increasing or decreasing the intensity automatically.

The bond strength improvement and reduction of adhesive interface degradation when self-etching adhesives are applied under electric current are reported in the literature [3,14,18,23,24], with emphasis on self-etching 2-step [23]. For some studies [3,23], the high bond strength values of self-etching adhesives, especially single-step adhesives, are justified by the fact that these adhesives have a higher hydrophilic polar monomer concentration, which facilitates the electric current distribution through the dentin substrate. Studies [13,15,20,23] that assessed the influence of the electric current technique on conventional adhesives also found positive results for tooth-restoration bond strength and satisfactory adhesive interface degradation. It is worth mentioning that a study by Guarda *et al.* [23] when evaluating the influence of 3 different adhesives with the use of electric current, stated that the highly hydrophilic nature of universal adhesives allows the movement of water inside the hybrid layer, even after photopolymerization. The fact that such adhesives act as a permeable membrane, due to the porosity within the malformed hybrid layer, suggests that even with the use of electric current, there is no significant increase in bond strength between the tooth and the restoration.

To establish an effective tooth-restoration bond, intimate contact between the adhesive and the dentin substrate is required. The wetting provided by the adhesives is a crucial factor in adhesion and is related to tooth surface energy, roughness, and chemical composition [14]. Reducing the contact angle between the adhesive and the tooth provides greater effectiveness in surface wetting and, consequently, improves the formation of hybrid layer and bond strength [34,35]. However, despite finding positive results in the hybrid layer formation of adhesives applied with the electric current device, the study carried out by Guarda [16] found no significant decrease in the contact angle when using the electric current. On the other hand, the study by Toledano *et al.* [14] found a relevant contact angle decrease when applying the electric current with self-etching adhesive. The presence of different components in the chemical composition of adhesive systems may justify the differences between the studies, since chemical reagents and resin monomers with different polarities and molecular weight can modify adhesive viscosity, making it difficult for the electric current to be transmitted [3]. Further studies concerning the relationship involving the adhesive materials' chemical composition and electric currents are required.

The study carried out by Quiles [22] performed an analysis involving modified primers with different functional monomers, MDP and MEP. He observed that the electric current does not influence the interaction of monomers with calcium ions but increases the bond strength



and decreases adhesive failures. The same study showed better adhesive results are obtained by using the electric current with adhesives that contain MDP. Longer chain hydrophobic functional (acid) monomers such as the MDP form salts that are much more stable to hydrolytic degradation, promoting greater long-term bond strength values compared to short-chain monomers such as MEP, which are more hydrophilic and susceptible to degradation [36]. Even in studies using thermocycling tests simulating the clinical longevity of restorations, the use of electric currents is effective for bond strength and nanoinfiltration results [20,24].

The application of electric current on resin cements does not influence adhesion values [19,21]. The high viscosity of resin cements and the high contact angle formed with the dental substrate [3] do not favor surface wetting and make it difficult for the electric current to pass through the adhesive and the dental substrate.

The iontophoresis technique improves the infiltration of adhesives into the dentin matrix, providing that the demineralized dentin is well filled by the adhesive, minimizing the deleterious effects caused by metalloproteinases [3,14,15]. Thus, the dental substrate becomes less permeable and with a better quality hybrid layer, improving restoration longevity [13].

## CONCLUSIONS

According to this present systematic review, the technique of electric current-induced adhesive systems brings positive results to the improvement of bond strength. However, it is important that other variables are tested to minimize divergences and to protocol an optimal current intensity. New research should compare the effect of the technique using different adhesive systems and its influence on the clinical restoration longevity. In addition, it is important to note that dentin is a very complex substrate and many *in vitro* studies may underestimate the results *in vivo*.

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