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INFLUENCE OF DIODE LASER ON EVAPORATION OF SOLVENTS IN ADHESIVE SYSTEMS

Influência do laser de diodo na evaporação de solventes em sistemas adesivos

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RESUMO

Objetivo: Avaliar a influência do laser de diodo, em diferentes potências e tempos, na evaporação do solvente de sistemas adesivos. **Materiais e métodos:** Foram testados dois sistemas adesivos convencionais (Adper Scotchbond Multi Purpose, 3M ESPE e Adper Single Bond 2, 3M ESPE) e dois sistemas adesivos autocondicionantes (Clearfil SE Bond, Kuraray e Optibond All-in-one, Kerr). Dez microlitros de cada sistema adesivo foram dispensados num recipiente de vidro côncavo e a perda de massa foi mensurada utilizando uma balança analítica digital. As técnicas de evaporação do solvente incluíram jato de ar a 10 cm por 5 segundos (técnica controle) e laser de diodo irradiado em modo contínuo a 1 cm de distância com potências de 1, 2 e 3 W durante 5, 10, 15, 20 e 25 segundos (técnicas experimentais). Foram efetuadas seis repetições (n=6) para cada adesivo e técnica. Os dados foram submetidos à análise de variância e ao teste de Tukey (α= 5%). **Resultados:** O laser de diodo provocou a evaporação do solvente dos sistemas adesivos. **Discussão:** O laser de diodo influenciou a evaporação do solvente, com maior potência e/ou tempo de exposição aumentando a taxa de evaporação. Ele pode ser uma alternativa ao método convencional, mas requer mais estudos clínicos. **Conclusão:** O ajuste da potência e do tempo de irradiação do laser de diodo mostrou-se capaz de favorecer a evaporação do solvente dos sistemas adesivos, indicando seu potencial para melhorar o desempenho desses materiais.

Palavras-chave: Lasers; Evaporação; Adesivos Dentinários; Solventes.

ABSTRACT

Aim: Evaluate the influence of diode laser at different power outputs and times on evaporation of the adhesive system solvent. **Materials and methods:** Two conventional adhesive systems (Adper Scotchbond Multi Purpose, 3M ESPE and Adper Single Bond 2, 3M ESPE) and two self-etching adhesive systems (Clearfil SE Bond, Kuraray and Optibond All-in-one, Kerr) were tested. Ten microliters of each adhesive system were dispensed in a concave glass container and the mass loss was measured using a digital analytical balance. Solvent evaporation techniques included an air drying stream at 10 cm for 5 seconds (control technique) and diode laser irradiated continuously at 1 cm distance with power outputs 1, 2 and 3 W for 5, 10, 15, 20 and 25 seconds (experimental techniques). Six repetitions (n=6) were performed for each adhesive and technique. The data were subjected to analysis of variance and Tukey tests (α= 5%). **Results:** The diode laser caused solvent evaporation of adhesive systems. **Discussion:** The diode laser influenced solvent evaporation, with higher power and/or longer exposure increasing evaporation rate. It may be an alternative to the conventional method but requires further clinical studies. **Conclusion:** Adjusting the power and irradiation time of the diode laser proved to be effective in promoting the evaporation of the solvent from adhesive systems, indicating its potential to improve the performance of these materials.

Keywords: Lasers; Evaporation; Dentin-Bonding Agents; Solvents.

INTRODUCTION

The development of adhesive systems has enabled the practice of conservative restorative dentistry, i.e., dentistry that allows greater preservation of the remaining tooth structure in its procedures[1]. In 1955, Buonocore[2] introduced the technique of acid-etch on enamel and later, due to the morphophysiological differences between dentin and enamel, Nakabayashi[3] consolidated the success of the dentin adhesive technique by establishing the definition of the hybrid layer. Since then, the adhesive system has been widely used in the clinical practice of dental surgeons.

Contemporary adhesive systems are composed of resin monomers and low levels of filler particles dissolved in volatile solvents such as water, acetone and ethanol being the most common types[1,4]. Solvents play a fundamental role in the adhesive process[5] because they act as carriers for resin monomers into demineralized dentin, mix with residual water to form an azeotrope, and, when evaporated, allow proper infiltration of the adhesive into the exposed collagen fibrils[6]. Moreover, they diminish the viscosity of the adhesive system[7], thereby providing improved wetting of the tooth structure[1].

Although, studies have suggested that after the solvent has performed its function, it must be completely eliminated[8] since the presence of residual solvent may generate a reduction in mechanical properties[9]. Moreover, it may decrease the adhesive polymerization[10], thus compromising the bond strength to the tooth structure[9].

Most probably, it would be impossible to remove all the solvent from adhesive systems before light-curing, however, it is fundamental to perform efficient clinical procedures that are capable of promoting the highest possible level of evaporation, for the purpose of forming more resistant polymers with less potential for degradation over time[1]. The manufacturers propose the method of applying an air-drying stream to potentiate solvent evaporation[8].

When a substance is heated there is an increase in the kinetic energy of its molecules, leading to a change in its state[11]. Therefore, researches have used a warm air-stream, resulting in higher rates of evaporation of adhesive system solvents[8,12,13].

In this context, the diode laser has emerged as a source of electromagnetic energy. When used at high power, it increases the local temperature through a photothermal interaction with the irradiated surface[14], which may promote the evaporation of adhesive solvents. Furthermore, the use of this laser has been suggested because it is a type of equipment composed of semiconductors. Since it is portable, simple and practical, it may be used on a daily basis in the dental clinic[15].

In 1999, Gonçalves et al.[16] proposed laser irradiation with Nd:YAG after application of the adhesive system and before light activation. This resulted in increased bond strength. The authors believed that there was the development of a substrate in which the dentin and adhesive were fused by action of the laser. While considering greater clinical feasibility, Maenosono et al.[14], used the diode laser to evaluate bond strength in simplified adhesive systems, and showed positive results. The underlying mechanism is still unknown, and an attempt to provide an explanation would be that the heat provided by laser irradiation could favor adhesive penetration and solvent evaporation[15].

Thus, the aim of the present in vitro study was to investigate the use of high-power diode laser for the evaporation of adhesive system solvents in comparison with the use of an air-drying stream for the same purpose. The conceptual hypothesis of this study was that the diode laser would cause a higher rate of solvent evaporation.

MATERIALS AND METHODS

This was an *in vitro* experimental study, in which four adhesive systems (two self-etching and two conventional) were tested for (rate of) solvent evaporation using different methods. The conventional adhesives used were Adper Scotchbond Multi Purpose (3M ESPE, St Paul, MN, USA) and Adper Single Bond 2 (3M ESPE, St Paul, MN, USA), and the two self-etching adhesive systems used were Clearfil SE Bond (Kuraray, Okayama, Japan) and Optibond All-in-one (Kerr Corporation, Orange, CA, USA) (Table 1).

Table 1 - Adhesive system characteristics: manufacturer, lot, classification and chemical composition

Adhesive Manufacturer Lot	**Classification**	**Composition (highlighting the solvent)**
Adper Scotchbond Multi Purpose - Primer 3M ESPE, St Paul, MN, USA N322814	Conventional of three steps	Primer: HEMA, copolymer of acrylic and itaconic acids and **water**
Adper Single Bond 2 3M ESPE, St Paul, MN, USA N261545	Conventional of two steps	Bis-GMA, HEMA, treated silica, glyicerol-1, 3-dimetacrilate, copolymer of acrylic acid and itaconic acid, Diurethane dimethacrylate, diphenyliodonium hexafluorophosphate, **water and ethanol**
Clearfil SE Bond - Primer Kuraray, Okayama, Japan 01109A	Self-etching of two steps	*Primer:* MDP, HEMA, hydrophilic dimethacrylate , N.N diethanol *p*-toluidine, camphorquinone, **water**
OptiBond All-In-One Kerr Corporation, Orange, CA, USA 4457104	Self-etching of one step	GPDM, monomer methacrylate and dysfunctional, camphorquinone, nano-silica, sodium hexafluorosilicate**, water, acetone** and **ethanol**

Legend:
HEMA: 2-Hydroxy-ethyl-methacrylate;
Bis-GMA: Bisphenol diglycidyl dimethacrylate;
GPDM: Dimethacrylate glycerol phosphate;
MDP: 10-Methacrylate dihydrogen phosphate.

The solvent evaporation rates were verified by the gravimetric method, in which the variation in mass of each sample was measured in an analytical digital balance (Bosh SAE 200, Bosh, Jungingen, BW, Germany) with a precision of

0.0001g, previously calibrated at the beginning of the laboratory stage and with constant monitoring of its calibration during the entire experimental practice.

For dispensing the adhesive system, a concave glass vessel, denominated glass clock (Uniglas, Porto Alegre, Rio Grande do Sul State, Brazil) was used, with a diameter of 60 mm and a depth of 10 mm. For each measurement, the glass was placed in the center of the balance and, after weighing the sample,(he weight was recorded) the balance was reset.

With a high-precision micropipette (Kacil Indústria e Comércio Ltda, Recife, Pernambuco state, Brazil) and disposable tips (Cral, Cotia, State of São Paulo, Brazil), 10 μL of each system tested was dispensed into the vessel. For the purpose of facilitating dosage of the material in the micropipette, the dispenser nozzle of the original package of each adhesive was previously removed and after use, the flask was immediately closed. After dosage, the excess adhesive on the tip was removed by using absorbent paper.

To dispense the adhesive system, the micropipette was held in place vertically so that the drop volume did not change. Right after putting the test material into the glass clock container, the initial mass value (mi) was recorded.

Afterwards, the solvent evaporation of each adhesive system was carried out in accordance with the following techniques:

Control technique: application of air-dry stream for 5 seconds (in accordance with the time described by the manufacturer) at a distance of 10 cm from the tooth surface, with standard pressure, applied by the same triple syringe. For the Clearfil SE Bond system, the time of 5 seconds of air-dry stream application was arbitrarily assumed since manufacturer did not inform the exact time for the procedure.

Experimental techniques: diode laser application The Laser Surgery (DMC Equipamentos Ltda, São Carlos, São Paulo state, Brazil), performed with a wavelength of 810 nm and fiber diameter of 400 μm, was applied in continuous mode, (with the tip kept a distance of 1 cm from the irradiated tooth surface, in the power outputs of 1 W, 2 W and 3 W for 5, 10, 15, 20 and 25 seconds, resulting in 15 irradiation combinations per adhesive. The corresponding energy density ranged from 4.000 J/cm^2 to 60.000 J/cm^2.

Immediately afterwards, the final mass value (mf) was recorded. For each one of the 4 adhesives, in each one of the 4 evaporation techniques evaluated, 6 measurements were taken (n=6) and, to allow application of the technique, the right and superior windows of the scale were kept open.

The variation between the initial (mi) and the final (mf) masses of samples, respectively, before and after application of the proposed evaporation protocols, were transformed into the outcome *solvent evaporation rate (SE)* using the following equation[17]:

$$SE = \left(\frac{mi - mf}{mi}\right) \times 100$$

All the procedures throughout the entire study were performed by the same operator, in a controlled environment at temperatures of 20 to 24 ºC and relative humidity of 50% monitored by thermo-hygrometer.

Statistical Analysis

The SE values were tabulated in spreadsheets and analyzed by descriptive statistics in the program SPSS (Statistical Package for Social Sciences, version 18.0). Normality of distribution was verified by the Shapiro-Wilk test, and the homogeneity by Levene’s test. The one-way ANOVA/Tukey tests were used to compare the SE among the 15 experimental groups and the control group.

RESULTS

ANOVA/Tukey analysis showed that the SE values were higher in the experimental groups with greater time evaporation and higher power output (Tables 2, 3, 4 and 5).

For the adhesive system Adper Scotchbond Multi Purpose, the only group in which the SE was significantly superior to the control was that using 3 W for 25 seconds. For Adper Single Bond 2, the SE was significantly higher when using 2 W or 3 W for 25 seconds. In the case of Clearfil SE Bond and Optibond All-in-

One, the SE values obtained with a power output of 3 W for 25 seconds were similar to those achieved with the air-dry stream.

Table 2 - Solvent evaporation rate (SE) – mean (standard deviation) of the adhesive system Adper Scotchbond Multi Purpose relative to the techniques and application times

Evaporation technique	**Application times**				
Air-dry stream	5 s	5 s	5 s	5 s	5 s
	3.28[a]	3.28[a]	3.28[a]	3.28[a,b]	3.28[a]
	(1.12)	(1.12)	(1.12)	(1.12)	(1.12)
Laser 1 W	5 s	10 s	15 s	20 s	25 s
	0.68[b]	1.37[b,c]	1.87[b]	2.07[b]	2.98[a]
	(0.08)	(0.17)	(0.74)	(0.57)	(0.51)
Laser 2 W	0.58[b]	1.12 [c]	2.05[a,b]	2.94[a,b]	3.72[a]
	(0.36)	(0.58)	(0.61)	(0.85)	(0.86)
Laser 3 W	1.16[b]	2.48[a,b]	3.22[a,b]	4.2[a]	6.21[b]
	(0.49)	(0.79)	(0.99)	(1.61)	(1.26)

Legend:
* Different letters represent significant statistical differences ($p<0.05$).
Each column represents the results of a Tukey test.

Table 3 - Solvent evaporation rate (SE) – mean (standard-deviation) of the adhesive system Adper Single Bond 2 in relation to the techniques and application times

Evaporation technique	**Application times**				
Air-dry stream	5 s	5 s	5 s	5 s	5 s
	4.53[a]	4.53[a]	4.53[a]	4.53[a,b]	4.53[a]
	(0.72)	(0.72)	(0.72)	(0.72)	(0.72)
Laser 1 W	5 s	10 s	15 s	20 s	25 s
	0.89[b]	1.89[b]	2.66[b]	3.11[b]	4.11[a]
	(0.53)	(0.76)	(0.80)	(1.99)	(0.81)
Laser 2 W	1.27[b]	2.73[b]	3.74[a,b]	4.86[a]	7.12[b]
	(0.82)	(0.59)	(0.71)	(1.01)	(1.01)

Evaporation technique	Application times				
Laser 3 W	1.06^{b}	2.26^{b}	4.14^{a}	5.08^{a}	7.20^{b}
	(0.39)	(0.87)	(0.77)	(0.63)	(0.77)

Legend:
*Different letters represent significant statistical differences (p<0.05).
Each column represents the results of a Tukey test.

Table 4 - Solvent evaporation rate (SE) – mean (standard deviation) of the adhesive system Clearfil SE Bond in relation to the techniques and to the application times

Evaporation technique	Application times				
Air-dry stream	5 s	5 s	5 s	5 s	5 s
	4.49^{a}	4.49^{a}	4.49^{a}	4.49^{a}	4.49^{a}
	(0.56)	(0.56)	(0.56)	(0.56)	(0.56)
Laser 1 W	5 s	10 s	15 s	20 s	25 s
	0.31^{b}	1.08^{b}	1.83^{b}	2.60^{b}	3.15^{b}
	(0.34)	(0.31)	(0.45)	(0.66)	(0.52)
Laser 2 W	0.21^{b}	1.46^{b}	2.67^{b}	3.01^{b}	4.22^{a}
	(0.33)	(0.69)	(1.20)	(1.07)	(0.68)
Laser 3 W	0.62^{b}	1.53^{b}	2.23^{b}	2.83^{b}	$3.93^{a,b}$
	(0.43)	(0.41)	(0.41)	(0.52)	(0.43)

Legend:
*Different letters represent significant statistical differences (p<0.05).
Each column represents the results of a Tukey test.

Table 5 - Solvent evaporation rate (SE) – mean (standard deviation) of the adhesive system OptiBond All-In-One in relation with the techniques and to the application times

Evaporation technique	Application times				
Air-dry stream	5 s	5 s	5 s	5 s	5 s
	37.8^{a}	37.8^{a}	37.8^{a}	37.8^{a}	37.8^{a}
	(2.43)	(2.43)	(2.43)	(2.43)	(2.43)
Laser 1 W	5 s	10 s	15 s	20 s	25 s

Evaporation technique	Application times				
	6.19^{c}	10.20^{c}	14.38^{c}	16.79^{c}	19.94^{c}
	(2.07)	(2.45)	(3.18)	(3.42)	(3.35)
Laser 2 W	11.24^{b}	16.9^{b}	21.56^{b}	22.04^{c}	27.51^{b}
	(1.46)	(2,66)	(2.73)	(4.61)	(2.78)
Laser 3 W	12.7^{b}	19.2^{b}	24.16^{b}	28.7^{b}	32.75^{a,b}
	(2.16)	(4.69)	(5.79)	(4.73)	(4.73)

Legend:
*Different letters represent significant statistic differences ($p<0.05$)
Each column represents the results of a Tukey test.

DISCUSSION

The conceptual hypothesis was partially accepted, because the study determined parameters of the diode laser that were able to increase the solvent SE of the adhesives, which more effective on conventional adhesives.

To interpret the results, we used a one-way ANOVA/Tukey's test to compare the SE among the 15 experimental groups and the control group, allowing us to identify significant differences between the irradiation protocols. This analytical approach follows the methodology of a previous study that evaluated similar solvent evaporation protocols for adhesive systems[18].

The several solvents used, such as water, acetone and ethanol have their own steam pressure characteristics and solubility parameters, and these properties influence the evaporation rate of these substances[19]. The adhesive Optibond All-in-One, which contains acetone as one of its solvents, had a higher SE. This fact may be explained since acetone showed the highest steam pressure values (184 mmHg at 20º C) and lowest solubility parameters (7 J/cm^3)[8,20], thus evaporating more rapidly than the other solvents (water and ethanol)[1].

Moreover, when using the air-dry stream, the results found for the adhesive systems Clearfil SE Bond and Adper Scotchbond Multi Purpose in the present study in comparison with Adper Single Bond 2 are in accordance with the results obtained by Abate et al.[17]. In the aforementioned study, the adhesive that had ethanol showed a higher evaporation rate when compared with products that contained water only. Nevertheless, because of the values found in this study, care must be taken when making comparisons with the results of other studies because there are several different parameters that might be used in the application of air-dry stream (time, pressure and distance).

According to Klein Jr et al.[21] solvent elimination aided by the warm air-stream resulted in higher evaporation rates when compared with these provided by the air-dry stream ambient temperature. In this context, the diode laser was used to evaluate its influence on solvent evaporation since its photo-thermal effect causes a rise in temperature on the target tissues during irradiation.

Moreover, the use of laser was proposed because the application of air-dry stream may cause the incorporation of oxygen into the adhesive, thereby compromising the polymerization and possibly leading to an adhesive failure[1]. In addition, the excessive use of air may cause the formation of pools of adhesive in the internal angles of the preparation; the adhesive layer may be contaminated with water; and also the adhesive may extend beyond the cavity limits[19].

However, when the laser was used during 5 or 10 seconds, this resulted in low evaporation rates for all the adhesives. This was probably because of the fact that, until there is a significant alteration in the temperature that may lead to a reduction in the mass loss, it takes time until the laser interacts with the adhesive system and produces heat.

Nevertheless, after the power output of 2W for 15s, for the system Adper Single Bond 2, and 3W for 10s for Adper Scotchbond Multi Purpose, the laser produced similar solvent evaporation results, in comparison with those of the air-dry stream. By using higher power and longer times, such as 2W for 25s and 3W for 25 s (Adper Single Bond 2) and 3W for 25s (Adper Scotchbond Multi Purpose), the technique with the laser promoted better results than the conventional technique. In view of the foregoing and since higher power outputs and/or longer times potentiated the interaction between the laser and the adhesive, it would be necessary to increase the time or the power output when the aim is to obtain a high solvent evaporation rate.

It is important to point out that the application of laser in the different parameters of time and power outputs used in the present study did not result in light-curing of the adhesive system. This can be explained because polymerization of the adhesive systems that contain camphorquinone as the photoinitiator agent, is started by blue light with a wavelength between 400 and 500nm[22]. Whereas the diode laser emits an infra-red light beam with a specific wavelength of 810 nm, which is not able to start the polymerization reaction of the adhesive systems.

According to Giannini et al.[23], when the adhesive system is simplified it has more complex formulations, in which the resin monomers are generally more acid and hydrophilic. Thus, the more hydrophilic the system is, the more it absorbs and retains water[24], which can reduce its evaporation rate. Thus, the SE results found in this study for Clearfil SE Bond and Optibond All-in-One may be explained because only the laser SE values obtained with the power output of 3 W for the time of 25 seconds, were similar to those of the air-dry stream.

Therefore, the diode laser emerges as an alternative for the solvent evaporation procedure. However, as this was an in vitro study, the results cannot be extrapolated to clinical practice.

Additional researchers must be conducted to evaluate the influence of the diode laser on the bond strength, degree of conversion of adhesive systems as well as to gain understanding of the interaction between the laser and the adhesive, and effect on the dentin surface and pulp vitality.

CONCLUSION

Based on the SE values obtained in this study, it can be concluded that the diode laser effectively promoted solvent evaporation from the adhesive systems when applied under higher irradiation parameters. In other words, higher power outputs and/or longer exposure times enhanced the interaction between the laser and the adhesive, thereby increasing solvent evaporation. Therefore, with the aim of improving the performance of adhesive systems through solvent evaporation, the use of the diode laser at higher power settings and/or for extended irradiation times may represent a feasible strategy.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

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