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Original Article

Self-Adhesive Resin Composites: Are they the Ultimate Bonding Solution?

Hebatallah Ahmed Saleh[1], Aya Adel El Tahlawy[2], Ahmed Adel Abdel Aziz[3]

[1]Conservative Dentistry Department, Faculty of Dentistry, Cairo University1
[2]Dental Biomaterials Department, Faculty of Dentistry, Cairo University
[3]Conservative Dentistry Department, Faculty of Oral and Dental Medicine, Badr University

Email: hebaallah.mahmoud @dentistry.cu.edu.eg

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Abstract

Aim: To evaluate the bond strength of self-adhesive flowable composite (SAFC) with or without bonding application and compare it to that of conventional flowable composite.
Subjects and methods A total of 15 extracted human premolars devoid of cavities were gathered. After the teeth were set individually in acrylic molds, the enamel was removed with a diamond disc and then dentin was flattened using silicon paper. The specimens were randomly divided into 3 groups: Group 1 was self-adhesive flowable composite without bonding, Group 2 was self-adhesive flowable composite with universal bonding agent application, and Group 3 was conventional flowable composite with universal bonding agent application. Two specimens were prepared on each tooth so that each group contains 10 specimens (n=10). Micro-shear bond strength was measured using universal testing machine, and mode of failure was assessed using stereomicroscope. **Results:** The median value of Group 1 (2.69 MPa) was significantly lower than that recorded in both Group 2 (17.09MPa) and Group 3 (9.96MPa).
Conclusion: The bond strength to the dentin substrate was compromised when self-adhesive flowable composite was used alone without prior bonding agent application.

Keywords: bond strength, self-adhesive flowable composite, Vertise Flow, failure mode.

Introduction

Bonding to dentin was and still one of the major challenges in restorative dentistry. It depends mainly on mineral exchange removed from dental substrate and replaced by resin which interlocks in the created micropores (Bektas et al., 2013).

Flowable resin composite was initially presented in 1990, offering advantageous features including straightforward clinical application and superior adaptation to cavity walls (ISO, 2003). A novel category of self-adhesive restorative composites has been created- self-adhesive flowable composites (SAFCs), which adhere to tooth enamel and dentin without the need for a separate application of adhesive solutions. This is the anticipated innovation for dentists, wherein self-adhering composites amalgamate the advantages of adhesive and composite technologies into a self-adhesive restorative composite material (Van Meerbeek et al., 2010). A new generation of self-adhesive flowable composites, which eliminate the need for separate etching, washing, and bonding operations, has recently been released to the market such as Vertise Flow, an eighth-generation self-adhesive composite. The application of self-adhesive resin composite reduces chair time and minimizes technical sensitivity and procedural errors, both of which are crucial in dental practice, particularly when treating young, uncooperative patients.

New products of self-adhering flowable composites are now in the market with limited information in literature that necessitates laboratory tests. Among laboratory tests, bond strength evaluation provides an assessment of bonding performance of adhesive materials, which is a property of clinical relevance with significant correlation to failure rates of bonded restorations (Altunsoy, Botsali, et al., 2015).

Thermal cycling replicates the exposure of the mouth cavity to severe temperatures and demonstrates the correlation of the linear coefficient of thermal expansion between dental and restorative materials. Thermal cycling exerts stress on the interface between resin and tooth, potentially compromising bond strength depending on the adhesive technique employed (Altunsoy, Tanrıver, et al., 2015).

The assessment of the bond performance of self-adhesive flowable composite to enamel and dentin, measured by micro-shear bond strength, proved to be significant for evaluating the newly introduced concept and its correlation to the clinical performance of this novel material (Sudsangiam & van Noort, 1999; Ferdianakis, 1998). This study aims to examine the micro-shear bond strength of self-adhesive flowable composite to dentin with or without bonding agent application and compare it to conventional flowable composite. The null hypothesis claimed that there would be no significant difference in micro-shear bond strength among the various groups.

Subjects and Methods

Ethical approval:

The current study was granted approval from Badr University in Cairo BUC Institutional ethical committee with approval number: BUC-IACUC-241020-114.

Sample size calculation:

Based on ***Sibai et al., 2022***, mean micro-shear bond strengths varied between 29.68 ±1.90, 36.25 ±0.60 and 26.58 ±1.33. The G*Power statistical power analysis program (version 3.1.9.4) indicates that a total sample size of 30 (with 10 specimens in each group) is adequate to identify a large effect size ($f = 0.62$), achieving an actual power ($1-\beta$ error) of 0.8 (80%) and a significance level (α error) of 0.05 (5%) for a two-sided hypothesis test ***(Yazici et al., 2013)***.

Selection of teeth, grouping and randomization:

A total of 15 extracted sound human premolars were obtained from oral surgery clinic of the faculty of dentistry and utilized in the present study. Teeth that were cracked, carious, or hypomineralized were omitted from the study. Each tooth was meticulously cleansed with an ultrasonic scaler until all calculus was eradicated. All teeth were subsequently submerged in normal saline containing 0.2% thymol disinfection solution until utilized ***(Bayne et al., 1998)***.

Teeth were affixed via their roots in self-cured acrylic resin blocks up to the cemento-enamel junction. The acrylic blocks were fabricated using cylindrical molds of 4 cm in height, 4 cm in diameter, and 0.5 cm in thickness, coated with a separating media ***(Fu et al., 2013)***. The mounted teeth were randomly divided into three groups, 5 teeth each according to the type of composite and adhesive system used. Group 1: Vertise Flow flowable composite without prior application of universal bonding agent. Group 2: Vertise Flow flowable composite with prior application of Prime&Bond universal bonding agent, and Group 3: Neo Spectra ST flow composite with prior application of Prime&Bond universal bonding agent. The above mentioned materials used in this study and their compositions are shown in Table (1).

Table (1): Materials used in the study and their composition

Material	Manufacturer	Batch number	Composition
Vertise™ Flow	Kerr Dental	10065690	GPDM adhesive and methacrylate co-monomers, HEMA, prepolymerized filler containing barium glass filler, nano-sized colloidal silica, nano-sized Ybf3 (70 wt.%)
Neo Spectra™ ST flow	Dentsply	2308000251	Barium-aluminium-borosilicate glass, Urethane modified Bis-GMA resin, Ytterbium fluoride, Ethoxylated Bisphenol-A-dimethacrylate,Dodecandiol, dimethacrylate,Trimethacrylate, Ethyl-4-dimethylaminobenzoate
Prime&Bond universal	Dentsply	2308000626	Ultra mild-etch (pH value > 2.5) adhesive formulation containing Bi- and multifunctional acrylate, phosphoric acid esters, isopropanol and water

Bis-GMA: bisphenol-aglycidylmethacrylate; GPDM: glycero-phosphate dimethacrylate; Ybf3: Ytterbium Fluoride; HEMA: 2 hydroxyethyl methacrylate.

Specimens preparation:

Teeth were abraded using a low-speed diamond disc and water coolant to eliminate coronal enamel until the underlying dentin was revealed *(Bayne et al., 1998)*. In Group 1, a rigid silicon tube of 0.9 mm internal diameter and 2 mm height was placed on the dentin surface followed by application of Vertise Flow composite directly inside the tube using its own syringe tip onto the dentin surface without the adhesive agent application step. The resin composite was cured for 20 seconds using LED light curing unit (Woodpeker WM-199, Foshan Vimel Denta Equipment Co. Guangdong, China) with a light intensity of 500 mW/cm^2 and a tip diameter of 7mm. After 24 hours, the tube was subsequently removed with a scalpel, and all specimens underwent further curing for 20 seconds. For Groups 2 and 3, to establish a uniform bonding area on the target surface, a segment of adhesive tape with a 2.5 mm diameter punched hole was affixed to the prepared tooth. Then, the adhesive was applied to the surface using a microbrush and spread using a gentle air stream until the liquid coating became imperceptible. Afterwards, light curing was performed for 20 seconds utilizing the light curing device. The rigid silicon tube with a 0.9 mm internal diameter and 2 mm height was placed on the dentin surface. The tube was subsequently filled with Vertise Flow flowable composite for Group 2, and Neo Spectra ST flow composite for Group 3. This was followed by light curing for 20 seconds from the unbounded surface. After 24 hours, the tube was subsequently excised using scalpel, and all specimens underwent further curing for 20 seconds. The light curing unit's efficiency was assessed for every 10 specimens utilizing a visible light curing radiometer. Two specimens were made on each tooth, resulting in a total of 10 specimens per group (n=10). Following the removal of silicon tubes, the dimensions of each composite cylinder was measured using digital caliper. After which, the specimens underwent 500 thermocycles (equivalent to 6 months) between 5 °C and 55 °C for 30 seconds each with dwell time 10 seconds using SD Mechatronic Thermocycler, Germany *(Fu et al., 2013)*.

Micro-Shear bond Strength Testing:

The acrylic blocks were affixed to the lower fixed head of the universal testing machine (Instron type 3345, England), as illustrated in Figure 1. Each specimen underwent a micro-shear bond strength (μSBS) test using a stainless-steel wire with a diameter of 0.14 inches, affixed to the upper movable head of the testing apparatus, positioned as near as feasible to the resin composite/dentin interface. A tensile force was exerted at a crosshead speed of 1.0 mm/min until specimen failure occurred. The force necessary for failure (in Newtons) was divided by the surface area (in mm²) to determine the micro-shear bond strength in MPa using the BlueHill 3 software from Instron, England.

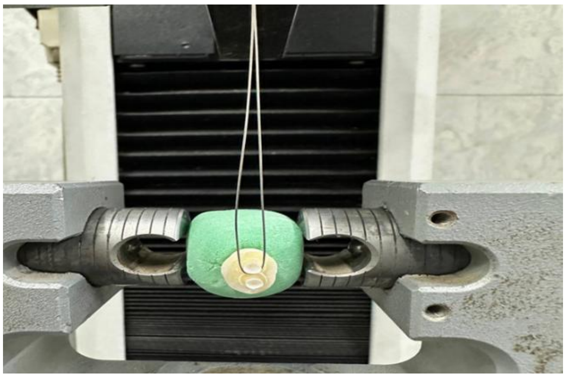

Figure (1): Acrylic blocks attached to the lower fixed head of the universal testing machine

Failure mode assessment:

The dentin surfaces at site of bonding to the composite resin were examined with a stereomicroscope (Kozo Optical and Electronical Instrumental, Nanjing, China) at a magnification of 40x. Failures were categorized as adhesive failure, cohesive failure, and mixed types. Adhesive failure occurred when no remaining bonding material was visible on the tooth surface. Cohesive failure of the adhesive was identified by residues covering the tooth surface along the whole diameter of the bonded area. Mixed failure was observed when the adhesive residue partially covered the bonded area.

Statistical analysis:

Statistical analysis was conducted utilizing a commercially available software application

(SPSS 20 - Statistical Package for Scientific Studies, SPSS, Inc., Chicago, IL, USA) for Windows. The data were assessed for normality by evaluating the distribution with the Kolmogorov-Smirnov and Shapiro-Wilk tests. Groups were compared using the post-hoc test. All P-values are two-sided. P-values ≤0.01 were deemed significant.

Results

Micro-Shear bond strength test results:

The results of micro-shear are presented in Table (2) and Figure (2). Post hoc test revealed statistically significant difference between groups (p=0.001). The results showed that the highest median value was recorded in Group 2 (universal bond + self-adhesive flowable composite) (17.09 MPa). This value was statistically significantly higher than that of both Group 3 (Universal bond + conventional flowable composite) (9.96 MPa) and Group 1 (Self-adhesive flowable composite alone) (2.69 MPa) which showed the lowest statistically significant median value.

Table (2): Descriptive statistics of micro-shear stress at Maximum load (MPa) and comparison between groups (Kruskal Wallis test)

Groups	Median	95% Confidence Interval		Range		Test value	P value
		Lower Bound	Upper Bound	Min	Max		
'Group 1' **Self-adhesive flowable composite alone**	**2.69^{a}**	**1.43**	**10.19**	**1.24**	**10.46**	**15.01**	**0.001***
'Group 2' **Universal bond+ self-adhesive flowable composite**	**17.09^{b}**	**13.72**	**26.08**	**4.39**	**32.11**		
'Group 3' **Universal bond+ conventional flowable composite**	**9.96^{c}**	**7.54**	**13.75**	**0.86**	**20.60**		

*Significance level p≤0.05, *significant, ns=non-significant*

Post hoc test: Within the same comparison, values sharing the different superscript letter are significantly different

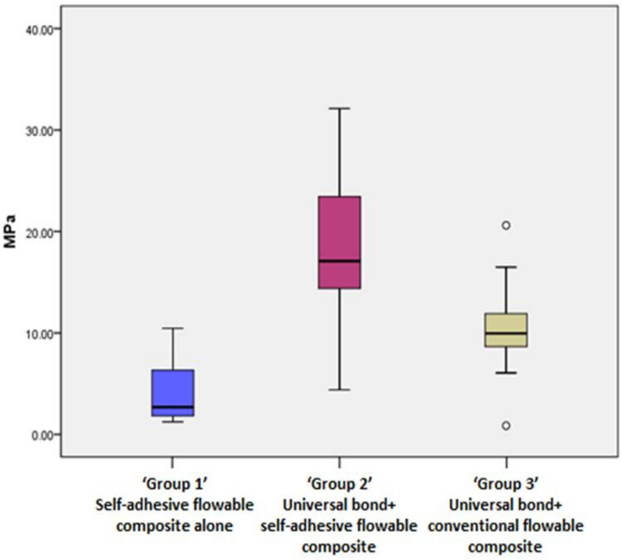

Figure (2): Box plot illustrating median value of micro-shear stress at Maximum Load [MPa] in different groups.

Failure mode analysis results:

After assessment using stereomicroscope, representative specimen from Group 1, Group 2 and Group 3 were shown in Figures (3a), (3b) and (3c) respectively. The failure mode analysis results showed that; adhesive failures were predominantly in Group 1, while Group 2 and Group 3 showed mixed type of failures.

Figure (3a): Adhesive failure shown in Group 1

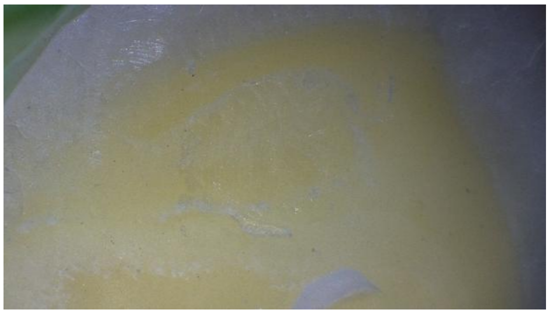

Figure (3b): Mixed failure shown in Group 2

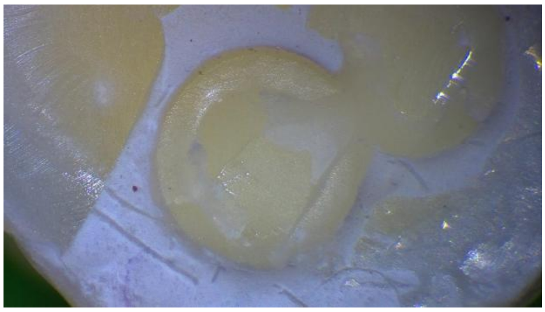

Figure (3c): Mixed failure shown in Group 3

Discussion

Nowadays, we are in the era of esthetic dentistry, where successful and durable esthetic restorations became a demand worldwide. The use of esthetic resin composite with efficient bonding is advantageous and of prime importance in modern dentistry ***(Altunsoy, Botsali, et al., 2015; Abdul Aziz et al., 2019)***.

Flowable composites, which were first introduced in 1990, are characterized by low viscosity with increased flowability than conventional resin composite. The decreased percentage of inorganic fillers in flowable composites lead to increased flow and reduction in its elastic modulus that improved its adaptability to cavity walls and margins ***(Tawfic et al., 2017; El- Refai, 2022)***.

Their main advantage, due to its high wettability, is the decrease in microleakage, postoperative hypersensitivity and internal voids. The flowable resin composite has a wide range of application as esthetic restorations in small cavities as in class I, III, V, pits and fissure sealant. In addition, it is being used recently as a base under universal composite, repairing of ceramic restoration, bonding of orthodontic brackets, restoring enamel defects and repair of incisal edges ***(Asiri et al., 2021)***.

Scientists and manufacturers have been constantly working since the introduction of adhesive dentistry to improve the clinical performance of the dental restorations ***(Hamdy & Gomaa, 2016)***. The improvement in adhesive dentistry has passed through several steps from the introduction of the 4th generation bonding agent which rely upon three-step etch and rinse adhesive system that was considered as the golden standard with highest bond strength. This was followed by the 5th generation two-step total etch adhesives, then challenges of simplifying clinical steps of bonding system through the innovations of 2 step self-etch adhesives which has the advantage of reducing technique sensitivity as it didn't require separate etching step and eliminating possibility of postoperative hypersensitivity resulting from etch and rinse adhesives ***(Hamdy & Gomaa, 2016; Sofan et al., 2016; Asiri et al., 2021)***. More simplifying of adhesive techniques has resulted in the appearance of 7th generation all-in-one bonding system, then finally the introduction of universal or Multi-Mode 8th generation adhesives which can be used as total etch, self-etch or selective etch mode to facilitate the dentist choice of the appropriate adhesive technique for each case in the clinic ***(Vasconcelos et al., 2020; Asiri et al., 2021)***.

For further simplification of the adhesive procedures, manufacturers have launched the self-adhesive flowable composites (SAFCs) which combines the benefits and merits of both adhesive and resin composite material technology in one product and one step delivery bringing novelty horizons to the operative procedures as it has the advantage of direct esthetic flowable composite material together with an adhesive resin in one step and considered a novel approach in the 8th Generation bonding system ***(Bektas et al., 2013; Celik et al., 2015; Naga et al., 2015)***.

Self-adhesive flowable composite resin is a direct composite resin restorative material that has the ability to bond to tooth structure without prior use of the bonding agent. It relies on technology that utilizes functional monomers to etch dentin. It also contains hydrophilic monomers that enhance wetting and resin penetration in dentin. This self-adhesive composite bonds in two ways, chemically between the phosphate functional groups of the monomer and calcium ions of the tooth, and micromechanically by an inter-penetrating network formed between the polymerized monomers and collagen fibers, in addition to the smear layer of dentin ***(Bektas et al., 2013)***.

Two types of self-adhesive flowable composites, Vertise Flow and Neo Spectra™ ST flow, are available in the market,. Both composites have acidic functional monomers in the composition of their resin matrix allowing bonding to enamel and dentin substrates without the need of separate etching and additional bonding steps ***(Baroudi & Rodrigues, 2015; El-Zainy et al., 2016; El- Refai, 2022)***.

Vertise Flow self-adhering flowable composite was used in this study and according to the manufacture technical profile, it is based on adhesive technology that utilizes functional acidic monomers (GPDM) to etch dentin. Also, it contains HEMA to increase the wettability, enhancing penetration of the resin into dentin thus increasing bonding strength ***(Poss, 2010; Naga et al., 2015; El- Refai, 2022)***.

Bonding mechanism of Vertise Flow to dentin occurs by two means; first is primary bond through the chemical chelation between phosphate functional monomers of GPDM and calcium ions of hydroxyapetite crystals of tooth. The other one is micromechanical bond that occurs between polymerized monomers of Vertise Flow with collagen fibers and smear layer of dentin with the resultant hybrid layer formation of resin impregnation to dentin. This secondary type of bond is achieved by the etching effect of the low pH of GPDM functional monomer.

From previous literatures, it was reported and observed that GPDM

Functional acidic monomer has mild etching similar to that of mild type self-etch that lead to formation of thin hybrid layer with weak bonding to the dentin. While others found no significant difference observed when using self-adhesive flowable composite according to the manufacturer instructions without preceding pretreatment bonding strategy due to its novelty. Hence, it seemed interesting to adopt further research to study its effect on bonding performance. Therefore, this study was conducted to investigate micro shear bond strength of self-adhesive flowable composite with and without prior use of bonding agent and compare it with conventional flowable resin composite ***(Poss, 2010; Marcelo et al., 2015; Abdul Aziz et al., 2019)***.

For ideal measurement of effectiveness and durability of bond strength, the specimens should undergo clinically relevant circumstances. Thermocycling is the most used method for artificial aging. A short thermocycling regimen was applied in this study, it consists of 500 cycles as recommended by ISO TR 11450 standard ***(ISO, 2003)***.

Micro-shear testing is one of the most commonly used methods for evaluating the bond strength. This test characterized by having small specimens which are easily manipulated and allow the testing of several specimens per tooth. In addition, testing small area minimizes the number of internal defects and allows for better stress distribution ***(Van Meerbeek B et al.,2010)***.

The null hypothesis of the current investigation was rejected as from the results obtained, there were statistically significant differences between different groups regarding micro-shear bond strength.

The results presented in Table (2) and Figure (2) showed that the highest median value of micro shear bond strength was recorded when using self-adhesive flowable composite with universal bond Prime&Bond, followed by conventional flowable composite while lowest bond strength was found when using self-adhesive flowable composite alone without preceding bonding steps.

Our results coincide with that of ***Poitevin et al., 2015 and Almaz et al., 2016*** who reported that bonding performance of SAFCs Vertise Flow was lower than that of conventional flowable composite used. Secondly, in agreement with ***Asiri et al., 2021*** who attributed these findings to GPDM phosphate monomer in Vertise Flow which has limited ability to etch and demineralize dentin substrate that may lead to weak micro-mechanical interlocking with resultant poor wetting of collagen fibers into dentin ***(El- Refai, 2022)***.

Other researchers as ***Bektas et al., 2013***, which have studied shear bond strength (SBS) of Vertise Flow, revealed that with the use of an adhesive system, Vertise Flow had greater SBS compared to when it used individually. This was in agreement with the results of our study as the use of adhesive system increased wettability to dentin and promote better infiltration of resin into dentin leading to the formation of durable and optimum hybrid layer ***(Altunsoy, Tanrıver, et al., 2015; Naga et al., 2015; Celik et al., 2015; Hamdy & Gomaa, 2016)***. Furthermore, the adhesive system used in this study with Vertise Flow was the Prime&Bond adhesive which is considered a universal isopropanol and water-based HEMA free adhesive system. It interacts chemically with dentin surface and has low pH of 2.1 that facilitate etching and result in the dissolving of smear layer and smear plug, allowing for clearing of dentinal tubules with enhanced dentin permeability and bond strength values ***(Shafiei & Memarpour, 2009; Hamdy & Gomaa, 2016; Pradeep et al., 2021)***. Furthermore, our results coincide with ***Abdul Aziz et al., 2019*** who found that SAFC which was not subjected to surface pretreatment has the lowest bond strength and attributed this to the fact that Vertise Flow has pH of 1.9 which interacts similar to mild self-etch adhesive on dentin substrate so result in mild etching of superficial dentin. Additionally, HEMA functional monomer present in SAFC is hydrophilic monomer which may attract water that was not evaporated from the bonded dentin to the resin leading to decrease in the micro-mechanical bond ***(Shadman et al., 2012; Gönülol et al., 2015)***. Furthermore, it was found in previous literatures that GPDM phosphate monomer present in SAFC might only etch rather than bond chemically to calcium in tooth structure, resulting in lowering bond strength ***(Rengo et al., 2012; Thorat et al., 2014; Tuloglu et al., 2014)***.

Similarly, our results were in agreement with that of ***Hamdy & Gomaa, 2016*** who found decreased SBS value of self-adhesive flowable composite (SAFC) when compared to conventional flowable composite. Their results were attributed to the weak etching action of SAFC that lead to its inability to penetrate into dentin and formation of thin and weak hybrid layer with short resin tags. Also, its inability to remove smear plug that was entrapped within bonded layer and plug opened dentinal tubules leading to decrease in bond strength.

The post hoc test in this study revealed significant difference between self-adhesive composite when applied without prior application of bonding agent and conventional flowable composite. This finding was not in agreement with other study conducted by ***Kamatchi M et al. 2022*** who found that SAFC had a significant higher bond than conventional flowable composite. This difference in the results may be attributed to the use of different type of commercially available SAFC and also the bond strength was measured using tensile bond strength test rather than micro-shear testing that was used in our study.

Regarding the failure mode analysis using stereomicroscope, it was observed (as shown in Figures (3a), (3b) and (3c)) that adhesive failures were predominantly in Group 1, which may be due to decreased wetting of the dentin with Vertise Flow and resultant formation of thin hybrid layer. On the other hand, mixed failures were seen in Group 2 and Group 3 showed mixed type of failures. Those results denote higher bond strength and adequate hybrid layer. No cohesive failure was seen in the specimens; it could be stated that the material's own cohesive strength was higher than the bond strength between the material and tooth substrate.

The results of this investigation were aligned with previous publications and literatures about SAFC. One of the limitations of this study is that only one type of SAFC Vertise Flow was used, while other types of self-adhesive composites may provide more accurate details about bonding performance of such materials. Furthermore, this study was carried out in-vitro, so additional clinical studies should be conducted to test bonding performance of such materials in the oral environment.

Conclusion:

Within the limitations of the present investigation, Vertise Flow self-adhesive flowable composite had the lowest bond strength compared to that used with a preceding bonding application. Therefore, eliminating bonding process has resulted in reducing bond strength which reflects poor bonding of self-adhesive flowable resin composite to dentin substrate.

Conflict of Interest:

The authors declare no conflict of interest.

Funding:

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors

Ethics:

This study protocol was approved by the ethical committee of the faculty of dentistry Badr University in Cairo, BUC Institutional ethical committee with approval number: BUC-IACUC-241020-114.

Data Availability:

Data will be available upon request

CRediT statement:

Author 1: Data curation, Writing - review & editing, Writing - original draft, Methodology, Conceptualization, Resources.

Author 2: Data curation, Conceptualization, Project administration, Supervision, Methodology, Writing - review & editing, Writing - original draft

Author 3: Methodology, Writing - original draft, Writing - review & editing, Investigation, Formal analysis, Supervision, Data curation.

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