Bond strength of self-adhesive flowable resin composites to tooth structure: a systematic review

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Aim: To review the current literature regarding the bond strength of self-adhesive flowable resin composites (SAFRCs) to tooth structure, comparing the outcomes with conventional flowable resin composites (CFRCs).

Methods: PubMed/Medline, EbscoHost and Scopus databases were screened (last update on November 2020) using related Medical Subject Headings (MeSH) and free terms. We included in vivo studies published in English language assessing the bond strength of SAFRCs and CFRCs to enamel and/or dentin from primary and/or permanent teeth. Results: In total, 23 articles were included. Unlike CFRCs, SAFRCs such as Vertise® Flow and Fusio™ Liquid Dentin exhibited statistically lower bond strength to enamel and dentin from permanent teeth. There were limited studies comparing the enamel bond strength of CFRCs and SAFRCs (prior phosphoric acid etching and/or adhesive system use). Also, we found few studies that evaluated the bonding effectiveness of Constic® and other SAFRCs to primary teeth. Conclusions: Current SAFRCs showed low bond strength to permanent teeth, which impedes to recommend them as a reliable alternative to CFRCs. The bonding performance of Constic® on both hard dental tissues should be evaluated on future studies. Also, more evidence assessing the bond strength of SAFRCs to primary teeth and etched enamel is needed.

Keywords: Composite resins. Dental bonding. Systematic review as topic.
Introduction

The simplification of dental techniques represents one of the main goals and tendencies in current restorative dentistry. Interestingly, clinical studies have shown that dental restorations performed with simplified dental materials such as universal adhesive systems, self-adhesive resin cements and bulk-fill resin composites have an acceptable performance\(^1\)\(^-\)\(^4\). Recently, another simplified dental materials known as self-adhesive flowable resin composites (SAFRCs) were introduced into the market. SAFRCs are indicated for pit and fissure sealants, base/liner and restorative material in small cavities\(^5\)\(^-\)\(^7\), the same clinical indications than conventional flowable resin composites (CFRCs). According to manufacturer’s instructions, SAFRCs could be used without previous phosphoric acid etching and adhesive systems, especially for dentin bonding procedures\(^5\)\(^-\)\(^7\). This was possible by acidic functional monomers such as glycerol phosphate dimethacrylate (GPDM), 10-methacryloyloxi-decyl-dihydrogen-phosphate (10-MDP) and 4-methacryloxyethyl trimellitic acid (4-META) incorporated into Vertise® Flow, Constic® and Fusio™ Liquid Dentin, respectively. These functional monomers establish a chemical interaction with inorganic phase of hard dental tissues which theoretically would guarantee acceptable bond strength. In some cases, only previous phosphoric acid etching on uncut enamel surface is recommended to increase the bond strength of SAFRCs\(^5\), but findings from some in vitro studies using this approach are controversial\(^8\)\(^-\)\(^9\).

SAFRCs could represent a good alternative to perform dental restorative/preventive procedures because they would reduce clinical time, operative errors and post-operative sensitivity\(^5\)\(^-\)\(^7\). Nonetheless, the number of clinical trials assessing the performance of SAFRCs restorations or pit and fissure sealants are extremely limited and controversial\(^10\)\(^-\)\(^12\) to contraindicate or recommend these novel dental materials. However, there are fairly available in vitro studies which evaluate microleakage, nanoleakage, solubility, water sorption and bond strength of SAFRCs\(^13\)\(^-\)\(^16\). This latter is one of the most important and critical features on self-adhesive materials due to it reflects the physico-chemical interaction with hard dental tissues, which could partially predict common clinical problems such as microleakage and retention loss. Until now, no consensus on the bonding effectiveness of SAFRCs has been established to determine if these novel dental materials could be used as a reliable alternative to conventional flowable resin composites (CFRCs). Therefore, a compilation of in vitro studies on this issue is urgently needed to indicate whether current SAFRCs should be used on future research or more technological developments are required. The aim of this study was to review the current literature regarding the bond strength of self-adhesive flowable resin composites to tooth structure, comparing the results with conventional flowable resin composites.

Materials and methods

The present systematic review was conducted following all parameters described in PRISMA guidelines (Preferred Reported Items for Systematic Reviews and Meta-anal-
The research question was: Do SAFRCs exhibit comparable enamel and dentin bond strength to CFRCs?

Selection criteria

We included studies that used human enamel and/or dentin from primary and/or permanent teeth, independently if dental substrates were cut, grounded and/or laser ablated (patient). The studies had to evaluate SAFRCs (intervention) such as Vertise® Flow, Fusio™ Liquid Dentin and/or Constic® used with or without previous phosphoric acid etching and/or adhesive system. Also, CFRCs (control/comparison) used as pit and fissure sealant and/or restorative material bonded by etch-and-rinse adhesive systems (ERAs), self-etch adhesive systems (SEAs) or universal adhesive systems (UAs). All included studies had to compare the bond strength between SAFRCs and CFRCs to enamel and/or dentin (outcome). Reports not published in English language, literature reviews, clinical studies, case reports/case series, book chapters, congress abstracts, editor letters and studies which exclusively evaluated the bond strength of experimental SAFRCs were excluded from the analysis of the current systematic review.

Search strategy and study selection

Different systematic searches were conducted by two trained and independent reviewers (C.M.T and S.M.P) until November 2020. We screened PubMed/Medline, EbscoHost and Scopus, using search strategies as follows; PubMed/Medline, ((((self-adhesive flowable composite resin) OR (self adhesive flowable resin composites)) OR (self-adhering flowable resin composite)) OR (self-adhering flowable composite resin) OR (vertise flow)) OR (fusio liquid dentin)) OR (constic)) AND (bond strength); Ebscohost, self-adhesive flowable composite resins OR self-adhesive flowable resin composite OR self-adhering flowable composite resin OR self-adhering flowable resin composite OR vertise flow OR fusio liquid dentin OR constic AND bond strength; Scopus, self-adhesive AND flowable AND resin AND composite OR self-adhesive AND resin AND composite OR self-adhering AND resin AND composite OR self-adhesive AND composite AND resin OR self-adhering AND flowable AND composite AND resin OR vertise AND flow OR fusio AND liquid AND dentin OR constic AND bond AND strength. Article titles were exported to Microsoft Excel® 2016 (Microsoft Corporation, Redmond, Washington, USA) to eliminate repeated hits in the same database and between them. Later, remaining titles and abstracts were screened in detail by two reviewers (C.M.T and S.M.P), excluding those that seem not to meet inclusion criteria. When abstracts presented limited information to be classified or seemed to meet all inclusion criteria, articles were downloaded for full-text reading. The titles were codified into 6 categories according to selection criteria, as follows: C1 (Articles not published in English language), C2 (clinical studies/case reports/case series), C3 (Articles which did not compare the bond strength of SAFRCs with CFRCs), C4 (Studies that exclusively evaluated the bond strength of experimental SAFRCs), C5 (Others types of papers such as literature reviews, book chapters, congress abstracts and editor letters) and C6 (included studies). Finally, reference lists from selected studies were screened in detail to find possible articles which could meet inclusion criteria.
Data extraction

Data extraction was performed by two trained reviewers (C.M.T and S.M.P), using a standardized form containing information such as first author name, publication year, sample size (n), type of teeth, tested materials, type of materials, dental substrate (enamel, dentin or both), bonding test, aging technique, sample dimensions/load speed, failure mode analysis and predominant failure mode in SAFRCs. If relevant methodological information was missed from a study, we contacted the correspondence author via e-mail. If no answer was received after 2 weeks, we sent other mail, requesting the same methodological information. Finally, if no response was obtained four weeks following the first attempt, the article was included in the systematic review with not reported data (NR).

Data analysis

After methodological data extraction, meta-analysis was considered inappropriate due to great methodological divergences among included studies, especially in terms of bonding tests, load speed, adhesive systems and CFRCs. Nevertheless, means and standard deviations of bond strength values of SAFRCs and CFRCs groups from individual studies, were extracted and tabulated, indicating statistically significant differences (p≤0.05) among groups.

Risk of bias assessment

Risk of bias assessment was conducted in duplicate by two trained reviewers (C.M.T and S.M.P) and both analyses were later contrasted to find possible inconsistencies. To assess evidence quality, we employed an adapted instrument previously used in other systematic reviews about dental adhesion18-19. This instrument contains the following domains or items: randomization, sample size calculation, teeth free of caries, sample with similar dimensions, failure mode evaluation, manufacturer instructions, single operator and operator blinded. Each item was checked in individual studies, judging as “Yes” when reported in the methodology, but if not, the specific domain received “No”. The number of positive responses obtained in each included study were counted to determine the overall risk of bias, as follows: high risk of bias (Yes:1 to 3), medium risk (Yes: 4 or 5) and low risk of bias (Yes: 6 to 8).

Results

Search and selection

Figure 1 summarizes the selection process, according to PRISMA guidelines. Overall, electronic searches on three databases yielded 196 articles. After excluding repeated hits, screening and full-text reading, 20 articles remained. Complementary searches resulted in 3 new papers that met inclusion criteria. Finally, 23 articles were included in the qualitative analysis of the current systematic review.
Figure 1. Selection process, according to PRISMA guidelines.

Study characteristics

Table 1 presents the main methodological aspects from included studies. In total, 23 *in vitro* studies met inclusion criteria (published between 2012 and 2019) and most of them (n=18) used permanent teeth (ranging from 30 to 160) for the bonding tests. The bond strength of SAFRCs to primary teeth was evaluated in six studies, published between 2013 and 2019. Vertise® Flow (Kerr Corp, Orange, CA, USA) (n=22) followed by Fusio™ Liquid Dentin (Pentron Clinical, Orange, CA, USA) (n=5) were the most tested SAFRCs, while Constic® was evaluated only in three studies.

The bond strength of SAFRCs was mainly assessed by shear bonding test (n=20) and tensile bonding test (n=3), using dentin (n=13), enamel (n=3) or both tissues (n=7) as substrates. Most studies tested the immediate bond strength of SAFRCs to enamel and dentin. Only six studies employed thermocycling as an aging method and the number of cycles varied from 500 to 5000 (temperature from 5°C to 55°C). Failure mode analysis was evaluated in 20 of 23 studies, using stereomicroscope/optical microscope, digital microscope and/or Scanning Electron Microscopy (SEM), showing a predominant adhesive failure pattern in SAFRCs groups.
Table 1. Main methodological data from included studies.

| Author (Year) | Sample size | Type of teeth | Tested Materials | Type of materials | Dental substrate | Bonding test | Ageing/technique | Sample dimension/Load speed | Failure mode analysis | Predominant failure mode in SAFRC |
|---------------|-------------|---------------|------------------|-------------------|------------------|--------------|----------------|-----------------------------|-----------------------|-------------------------------|
| Juloski J (2012) | Enamel (n=50) Dentin (n=50) | Permanent molars | PA + OptiBond™ FL + Premise™ flowable OptiBond™ XTR + Premise™ flowable Vertise Flow® PA + Vertise Flow® | ERAs + CFRC | Enamel and dentin | SBS | Not / NA | 3mm in diameter / 0.5mm/min | Stereomicroscope | AF |
| Wajdowicz (2012) | NR | Third molars | Vertise Flow® Fusio™ Liquid Dentin PA + Optibond™ FL + Vertise Flow® PA + Optibond™ FL + Fusio™ Liquid Dentin PA + Optobond™ FL + Revolution™ | SAFRC | Enamel | SBS | Not / NA | 2.4mm in diameter / 1mm/min | Stereomicroscope | AF in Fusio™ Liquid Dentin |
| Vichi A (2013) | Enamel (n=60) Dentin (n=60) | Permanent molars | EasyBond® + Filtek™ Supreme XT Flow Xeno® V + X Flow® G-Bond™ + Gradia® Direct LoFlo AdheSE One® + Tetric EvoFlow® iBond® + Venus Flow® Vertise Flow® | 1S-SEAs+CFRC | Enamel and dentin | SBS | Not / NA | 3mm in diameter / 0.5mm/min | Optical microscope | AF |
| Pacifici E (2013) | 50 | Primary molars | Optibond™ All-In-One+Premise™ Supreme XT Flow PA + Optibond™ FL+Premise™ Flow PolyA+Fiji I® PolyA+Fiji II® Vertise Flow® | 1S-SEAs+CFRC | Dentin | SBS | Not / NA | 3mm in diameter / 1mm/min | Stereomicroscope | AF |
| Yazici AR (2013) | 80 | Permanent molars | PA+Optibond™ Solo Plus+Premise™ Flow Vertise Flow® | ERAs+CFRC | Dentin | SBS | Not / NA | 2.38mm in diameter / 1mm/min | Optical microscope | AF |
| Margvelashvili M. (2013) | 30 | Permanent molars | PA + Vertise Flow® PA + Guardian Seal® Adper™ Prompt L-Pop + Clinpro™ Sealant | SAFRC | Enamel | SBS | Not / NA | 3mm in diameter / 0.5mm/min | Optical microscope | SEM |
| Bektas OO (2013) | 30 | Third molars | Optibond™ All-In-One + Revolution™ Formula2 Vertise Flow® Optibond™ All-In-One + Vertise Flow® | 1S-SEAs+CFRC | Dentin | μSBS | Not / NA | 0.7mm in diameter / 1mm/min | NA | NA |
| Troconis et al. (2013) | Poitevin A (2013) | Tuloglu N (2014) | Russo D (2014) | Yuan H (2015) | Schuldt (2015) |
|---|---|---|---|---|---|
| Troconis et al. | Poitevin A | Tuloglu N | Russo D | Yuan H | Schuldt |
| Enamel (n=40) | Enamel | Enamel | Enamel | Enamel | Enamel |
| Dentin (n=55) | Dentin | Dentin | Dentin | Dentin | Dentin |
| Enamel (n=40) | Enamel | Enamel | Enamel | Enamel | Enamel |
| Dentin (n=55) | Dentin | Dentin | Dentin | Dentin | Dentin |
| Enamel (n=40) | Enamel | Enamel | Enamel | Enamel | Enamel |
| Dentin (n=55) | Dentin | Dentin | Dentin | Dentin | Dentin |
| Fusio™ Liquid Dentin Adhesive | Vertise Flow® | Vertise Flow® | Vertise Flow® | Vertise Flow® | Vertise Flow® |
| AdheSE Plus® + Filtek Z500 Flowable | Smart Cem® | PA + Optibond FL + Premise ™ Flowable | Ketac™ Conditioner Refill + Ketac™ Fil Plus | PA + Optibond FL + Premise ™ Flowable | PA + Const¢® |}

Table 1. Continuation.
| Study | Participants | Preparation | Adhesives | Bonding Technique | Material | TBS/µTBS | Methodology | SEM AF | Complementary Methods |
|-------|--------------|-------------|-----------|-------------------|----------|----------|-------------|--------|-----------------------|
| Sachdeva P (2016) | 60 primary teeth | Dyad™ Flow<sup>®</sup> Fusio™ Liquid Dentin Adhesive (NR) + G-aenial Universal Flo® | SAFRC SAFRC NR CFRC | Dentin | SBS | Not / NA | 2.5mm in diameter / 0.5mm/min | NA | NA |
| Memarpour M (2016) | Enamel (n=60) Dentin (n=60) primary canines | OptiBond™ All-In-One + Premise™ Flowable Vertise Flow® OptiBond™ All-In-One + Vertise Flow® | 1S-SEA+CFRC SAFRC 1S-SEA+SAFRC | Enamel and dentin | SBS | Not / NA | 3mm in diameter / 1mm/min | Digital microscope | AF and MF. |
| Almaz M, (2016) | 48 permanent molars | Vertise Flow® Clearfil™ SE Bond+Clearfil™ Majesty Flow All-Bond SE® + Aelite™ Flo Adper™ Easy One + Filtek™ Ultimate Flow | SAFRC 2S-SEAs+CFRC 1S-SEA+CFRC 1S-SEA+CFRC | Dentin | SBS | Not / NA | 3mm in diameter / NR | Illuminated microscope | AF |
| Moslemi (2016) | 40 third molars | SiC + Er, Cr: YSGG laser + Single-Bond® + CFRC(NR) SiC + Er, Cr: YSGG laser + Dyad™ Flow<sup>®</sup> SIC + Single-Bond® + CFRC (NR) SIC + Dyad™ Flow<sup>®</sup> | ERAs+CFRC SAFRC ERAs+CFRC SAFRC SAFRC SAFRC | Dentin | µSBS | Not / NA | 0.7mm in diameter / 0.5mm/min | Stereomicroscope | AF in SAFRCs without laser. |
| Bumrungruan (2016) | 60 third molars | Vertise Flow® PA + OptiBond™ FL + Premise™ Flowable OptiBond™ All-In-One + Premise™ Flowable | SAFRC ERAs+CFRC 1S-SEA+CFRC | Dentin | µSBS | Between 5C and 55C for 5000 cycles | 0.8 in diameter / 1mm/min | Stereomicroscope | AF |
| Durușlar S (2017) | 60 primary molars | Vertise Flow® G-aenial Bond® + G-aenial Universal Flo® PA + Tetric® N-Bond + Tetric® N-Flow | SAFRC 1S-SEA+CFRC ERAs+CFRC | Dentin | µTBS | Not / NA | 3mm in diameter / 1mm/min | SEM | AF |
| Peterson J (2017) | Enamel (n=64) Dentin (n=64) permanent molars | Constic® Fusio™ Liquid Dentin Vertise Flow® PA + Optibond™ FL + Venus Diamond Flow® | SAFRC SAFRC SAFRC ERAs+CFRC ERAs+CFRC SAFRC SAFRC | Enamel and dentin | SBS | TC (5000 cycles (between 5°C and 55°C) | 3mm in diameter / 1mm/min | Stereomicroscope | AF |
| Brueckner C (2017) | Enamel (n=80) Dentin (n=80) permanent molars | Vertise Flow® Fusio™ Liquid Dentin Adper™ Prompt L-Flow + Filtek™ Supreme XT flowable | SAFRC SAFRC SAFRC SAFRC 1S-SEA+CFRC 1S-SEA+CFRC | Enamel and dentin | SBS | TC (1900 cycles (between 5°C and 55°C) | 3mm in diameter / 0.75 ± 0.25 mm/min | SEM | AF |

**Table 1. Continuation.**
| Table 1. Continuation. |
|------------------------|
| **Rangappa A** (2018) | 64 | Permanent molars | Conстic® Dyad™ Flow<sup>Δ</sup> | SAFRC | SAFRC | Dentin | SBS | Not / NA | 3mm in diameter / 1mm/min | SEM | AF |
| **Poorzandpoush** (2019) | 48 | Primary canines and first molars | OptiBond™ FL+ Premise™ Flowable Vertise Flow® | ERAs+CFRC | SAFRC Dentin SBS | 1000 cycles between 5-55°C | 3mm in diameter / 1mm/min | Stereomicroscope | AF |
| **Abdelraouf** (2019) | Enamel (n=24) Dentin (n=12) | Permanent molars | Dyad™ Flow<sup>Δ</sup> | SAFRC UAs+CFRC | Enamel and dentin | SBS | Not / NA | 3mm in diameter / 0.5mm/min | Digital microscope | AF |

NA: not applied; NR: not reported; PolyA: Polyacrylic Acid; PA: Phosphoric acid; SiC: silicon carbide sandpaper; SBS: Shear bond strength; µSBS: micro-shear bond strength; µTBS: Micro-tensile bond strength; SEM: Scanning Electron Microscopy; Feg-SEM: field-emission gun scanning electron microscopy; 1S-SEAs: one-step self-etch adhesive system; 2S-SEAs: two-steps self-etch adhesive system; ERAs: etch and rinse adhesive; UAs: universal adhesive system; SARC: self-adhesive resin cement; SAGIC: self-adhesive glass ionomer cement; TC: Thermocycling; AF: adhesive failure; CF: cohesive failure; MF: mixed failure. Δ Vertise® Flow is marketed as Dyad™ Flow in some countries.

Optibond™ FL (Kerr, Orange, CA, USA), Premise™ Flowable (Kerr, Orange, CA, USA), Optibond™ XTR (Kerr, Orange, CA, USA), Vertise Flow ® (Kerr, Orange, CA, USA), Fusio™ Liquid Dentin (Pentron Clinical, Orange, USA), Revolution™ (Kerr, Orange, CA, USA), EasyBond (3M ESPE, St. Paul, MN, USA), Filtek™ Supreme XT Flow (3M ESPE, St. Paul, MN, USA), Xeno® V (Dentsply, Detrey, Kostanz, Germany), X Flow® (Dentsply, Detrey, Kostanz, Germany), Optibond™ XTR (Kerr, Orange, CA, USA), OptiBond™ Solo Plus (Kerr, Orange, CA, USA), Filtek™ Supreme XT Flow (3M ESPE, St. Paul, MN, USA), Smart Cem® (Dentsply, York, PA, USA), RelyX™ Unicem (3M ESPE, Germany), SpeedCem® (Dentsply, York, PA, USA), Adper™ Easy One (3M ESPE, St. Paul, MN, USA), Filtek™ Z350 Flowable (3M ESPE, St. Paul, MN, USA), All Bond SE® (Bisco Inc, Schaumburg, IL, USA), Aelite™ Flo (Bisco Inc, Schaumburg, IL, USA), Single Bond® (3M ESPE, St. Paul, MN, USA), G-aenial™ Bond (GC, Tokyo, Japan), Universal Single Bond® (3M ESPE, Germany).
Risk of bias assessment

Table 2 summarizes the risk of bias of the included studies. Only one of the studies reported sample size was calculated, but none of the studies reported if operators were blinded. Most included studies (n=21) did not report in the methodology section whether experiments were conducted by a single operator. Conversely, aspects such as randomization, teeth free of caries, samples with similar dimensions and manufacturer instructions were reported. Overall, 20 studies scored medium risk of bias, two studies had low risk and other one scored high risk.

Synthesis of results

Enamel Bond Strength of SAFRCs and CFRCs

Table 3 presents means, standard deviations and statistically significant differences on enamel bond strength between SAFRCs and CFRCs. Mean enamel bond strength of SAFRCs (without prior phosphoric acid etching and/or adhesive system use) in permanent teeth showed the following variations: Vertise® Flow (from 2.0 to 15.3 MPa), Fusio™ Liquid Dentin (from 3.0 to 13.0 MPa) and Constic® (from 3.9 to 4.5 MPa). Overall, mean bond strength of SAFRCs to previously etched enamel varied from 9.87 to 23.1 MPa. Conversely, the mean enamel bond strength of CFRCs associated with different types of adhesive systems ranged between 5.0 and 28.0 MPa in permanent teeth. The only study that used primary teeth to evaluate the bond strength of a SAFRC (Vertise® Flow) reported mean values of 9.29 MPa and 14.84 MPa for SiC and laser treated surfaces, respectively. Most studies showed significant lower enamel bond strength values on SAFRCs compared to CFRCs.

Dentin bond strength of SAFRCs and CFRCs

Table 4 presents means, standard deviations and significant differences on dentin bond strength between SAFRCs and CFRCs. Mean bond strength values of SAFRCs used without prior phosphoric acid etching and/or adhesive system use in permanent teeth showed the following variations: Vertise® Flow (from 1.0 to 32.66 MPa), Fusio™ Liquid Dentin (from 2.8 to 17.7 MPa) and Constic® (from 0.8 to 12.2 MPa). Overall, the bond strength of SAFRCs used on previously etched dentin or associated to an adhesive system ranged between 5.48 and 35.08 MPa. Two studies employed thermocycling and the results revealed that bond strength of Fusio™ Liquid Dentin decreased from 4.4 MPa to 1.6 MPa following thermocycling while the values for Vertise® Flow diminished from 3.0 to 1.0 MPa and from 22.1 to 21.1 MPa. Six studies evaluated the bonding performance of SAFRCs to primary teeth without prior acid etching or adhesive system use. The mean dentin bond strength values were: Vertise® Flow (from 2.3 to 12.17 MPa) and Fusio™ Liquid Dentin (14.15 MPa). Two studies evaluated the dentin bond strength of Vertise® Flow associated to Optibond™ All-In-One adhesive system and mean bond strength ranged between 8.7 and 16.89 MPa. On the other hand, mean bond strength of CFRCs associated to different adhesive systems varied from 14.87 to 21.11 MPa. Overall, most studies reported statistically significant lower dentin bond strength on SAFRCs compared to CFRCs groups.
Table 2. Risk of bias assessment in included studies.

| Author                  | Randomization | Sample size calculation | Teeth free of caries | Sample with similar dimensions | Failure mode evaluation | Manufacturer’s instructions | Single operator | Operator blinded | Risk of bias |
|-------------------------|---------------|-------------------------|----------------------|--------------------------------|-------------------------|-----------------------------|-----------------|-----------------|--------------|
| Juloski et al⁹           | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | No              | No              | Medium       |
| Wajdowicz et al¹⁰        | No            | No                      | Yes                  | Yes                            | Yes                     | Yes                         | No              | No              | Medium       |
| Vichi et al¹¹            | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | Yes             | No              | Low          |
| Pacifici et al²²         | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | No              | No              | Medium       |
| Yazici et al²²           | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | No              | No              | Medium       |
| Margvelashvili et al²⁴   | Yes           | No                      | Yes                  | No                             | Yes                     | Yes                         | Yes             | No              | Medium       |
| Bektas et al²⁵           | Yes           | No                      | Yes                  | Yes                            | No                      | Yes                         | Yes             | No              | Medium       |
| Poitevin et al⁹          | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | No              | No              | Medium       |
| Tuğrul et al²⁶           | Yes           | No                      | Yes                  | No                             | Yes                     | No                          | Yes             | No              | High         |
| Russo et al²⁷            | Yes           | No                      | Yes                  | Yes                            | Yes                     | No                          | No              | No              | Medium       |
| Yuan et al²⁸             | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | No              | No              | Medium       |
| Schuldt et al²³          | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | Yes             | No              | Medium       |
| Sachdeva et al¹⁶         | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | No              | Yes             | Medium       |
| Memarpour et al³⁰        | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | Yes             | No              | Medium       |
| Almaz et al²⁷            | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | Yes             | No              | Medium       |
| Moslemi et al²²          | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | Yes             | No              | Medium       |
| Bumrungruan et al³¹       | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | Yes             | No              | Medium       |
| Duruṣṣar et al³⁴         | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | Yes             | No              | Medium       |
| Peterson et al³¹          | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | Yes             | No              | Medium       |
| Brueckner et al³⁶        | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | Yes             | No              | Medium       |
| Rangappa et al³⁷          | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | Yes             | No              | Medium       |
| Poorzandpoush et al³⁸     | Yes           | Yes                     | Yes                  | Yes                            | Yes                     | Yes                         | Yes             | No              | Low          |
| Abdelraouf et al³⁹        | Yes           | No                      | Yes                  | Yes                            | Yes                     | Yes                         | Yes             | No              | Medium       |
Table 3. Means, standard deviations and statistically significant differences on enamel bond strength between SAFRCs and CFRCs.

| Author (year) | Materials | Enamel Bond Strength in MPa | Significant difference |
|---------------|-----------|-----------------------------|------------------------|
| **Permanent teeth** | | | |
| Juloski (2012) | PA + OptiBond™ FL + Premise ™ flowable | 16.83±2.93 | A |
| | PA + Vertise Flow® | 9.87±4.24 | B |
| | OptiBond™ XTR + Premise ™ flowable. | 8.59±4.39 | B |
| | PA + OptiBond™ XTR + Premise ™ flowable. | 7.04±3.63 | |
| | Vertise Flow® | 6.61±2.41 | B |
| Wajdowicz (2012) | PA + OptiBond™ FL + Vertise Flow® | 10.2±NR | A |
| | PA + OptiBond™ FL + Fusio™ Liquid Dentin | 8.5±NR | A |
| | PA + OptiBond™ FL + Revolution™ Fusio™ Liquid Dentin | 8.3±NR | A |
| | Vertise Flow® | 7.04±3.63 | B |
| | Vertise Flow® | 3.6±NR | B |
| Vichi A (2013) | EasyBond + Filtek™ Supreme XT Flow | 12.1±5.0 | A |
| | Xeno® V + X Flow® | 10.4±4.0 | AB |
| | G-Bond™ + Gradia® Direct LoFlo | 7.7±1.9 | ABC |
| | AdheSE One + Tetric Evo Flow® | 6.0±4.0 | BCD |
| | iBond® + Venus Flow® | 5.0±1.8 | CD |
| | Vertise Flow® | 2.6±2.6 | D |
| Margvelashvili (2013) | PA + Vertise Flow® | 17.9±2.9 | A |
| | Adper™ Prompt L-Pop + Clinpro™ Sealant | 12.9±6.0 | AB |
| | PA + Guardian Seal | 11.7±4.6 | B |
| Poitevin (2013) | Adper™ Prompt L-Pop + Filtek™ Supreme XT Flowable | Bur-cut:28.0±9.8/Sic- | A/A |
| | PA + Vertise Flow® | Ground:25.5±8.2 | |
| | Fusio™ Liquid Dentin | Bur-cut:23.1±7.1/Sic- | A/A |
| | Vertise Flow® | Ground:22.6±7.6 | AB |
| | EasyBond + Filtek™ Supreme XT Flow | Bur-cut:13.0±4.3/Sic- | B/B |
| | Xeno® V + X Flow® | Ground:10.8±5.8 | |
| | G-Bond™ + Gradia® Direct LoFlo | Bur-cut:11.0±4.2/Sic- | Ground:15.3±6.0 |
| Schuldt (2015) | PA + Helioseal F® | 19.1±6.2 / TC:15.6±4.4 | A/A |
| | PA + Constic® | 17.1±5.1 / TC:13.0±3.8 | A/AB |
| | Constic® | 4.3±3.6 / TC:3.9±1.4 | C/C |
| Peterson (2017) | PA+Optibond™ FL + Venus Diamond Flow® | 13.0±5.1 | A |
| | Constic® | 4.5±NR | B |
| | Fusio™ Liquid Dentin | 3.0±NR | B |
| | Vertise Flow® | 2.0±NR | B |
| Brueckner (2017) | Adper™ prompt L-pop + Filtek™ Supreme XT Flowable | 9.8±3.6 / TC: 8.3±3.7 | A/A |
| | Experimental flowable | 4.4±3.0 / TC: 0.7±0.4 | B/B |
| | Vertise Flow® | 4.0±2.1 / TC: 0.4±0.4 | B/BC |
| | Fusio™ Liquid Dentin | 3.5±2.3 / TC: 0.5±0.1 | C/C |
| Abdelraouf (2019) | PA+ Universal Single Bond®+ Filtek™ Z350-XT | Uncut: 24.6±6.2/ Cut: 12.7±4.5 | A/B |
| | Dyad™ Flow™ | Uncut: 3.5±1.6/ Cut: 4.5±2.7 | C/C |
| **Primary teeth** | | | |
| Memarpour (2016) | OptiBond™ All-In-One+Vertise Flow® | SIC:15.0±5.2.12 / Er:YAG laser:16.16±3.16 | A/A |
| | OptiBond™ All-In-One+Premise ™ Flowable | SIC:13.0±5.2.36 / Er:YAG laser:13.90±2.76 | A/A |
| | Vertise Flow® | SIC9.29±1.56 / Er:YAG laser:14.84±1.32 | B/A |

Different capital letters mean statistically significant difference (p≤0.05) among study groups, reported on individual studies.

SIC: silicon carbide sandpaper; PolyA: Polyacrilic Acid; PA: Phosphoric acid; TC: thermocycling; NR: Not Reported; Er:YAG laser: erbium:yttrium aluminum garnet laser. △Vertise® Flow is marketed as Dyad™ Flow in some countries.
Table 4. Means, standard deviations and statistically significant differences on dentin bond strength between SAFRCs and CFRCs.

| Author (year) | Materials | Dentin Bond Strength in MPa | Significant difference |
|---------------|-----------|----------------------------|------------------------|
| Troconis et al. | | | |
| Juloski (2012) | OptiBond™ XTR + Premise™ flowable | 10.60±5.0 | A |
| | PA + OptiBond™ XTR + Premise™ flowable | 9.60±4.91 | A |
| | PA + OptiBond™ FL + Premise™ flowable | 8.15±3.88 | AB |
| | PA + Vertise Flow® | 5.48±4.94 | BC |
| | Vertise Flow® | 2.94±2.79 | C |
| Troconis et al. | EasyBond + Filtek™ Supreme XT Flow | 12.2±3.6 | A |
| | AdheSE One + Tetric Evo Flow | 11.3±5.7 | A |
| | Xeno® V + X Flow | 10.7±4.7 | A |
| | G-Bond™ + Gradia® Direct LoFlo | 6.9±3.2 | AB |
| | iBond® + Venus Flow® | 5.8±1.2 | AB |
| | Vertise Flow® | 3.4±1.6 | B |
| Troconis et al. | PA+ OptiBond™ Solo Plus + Premise™ Flow | SIC:14.64±6.75 / Er:YAG laser:16.81±6.76 | A/A |
| | Vertise Flow® | SIC:7.92±2.91 / Er:YAG laser:12.61±3.49 | B/A |
| Troconis et al. | Optibond™ All-In-One/Vertise flow® | 35.08±7.0 | A |
| | Optibond™ All-in-one/ Revolution™ Formula2 | 29.33±5.19 | B |
| | Vertise Flow® | 23.70±5.28 | C |
| Troconis et al. | PA+Optibond™ FL + Premise™ Flowable | Xeno® V + X-Flow® | A/NA/NR |
| | Adper™ Prompt L-Pop + Filtek™ Supreme XT Flowable | iBond® + Venus Flow® | A/NA/NA/NR |
| | | PA + Vertise Flow® | B/B |
| | | Fusio™ Liquid Dentin | C/NRC/C/C |
| | | AdheSe One® + Tetric EvoFlow® Vertise Flow® | | |
| Troconis et al. | Optibond™ All-In-One/Vertise flow® | 35.7±2.9 | A |
| | Optibond™ All-In-One + Vertise Flow® | 25.6±3.0 | B |
| | Vertise Flow® | 19.3±2.3 | C |
| Troconis et al. | Optibond™ XTR + Premise™ Flowable | 25.3±13.0 | A |
| | PA+Optibond™ FL + Premise™ Flowable | 20.8±7.8 | A |
| | Smart Cem2® | 11.6±6.9 | B |
| | RelyX™ Uncem 2 | 11.3±7.3 | BC |
| | SpeedCem® | 10.7±5.5 | BCD |
| | MaxCem Elite™ | 9.6±5.3 | BCDE |
| | Vertise Flow® | 7.1±4.0 | CDE |
| | RelyX™ Uncem | 6.3±3.2 | DE |
| | Ketac™ Fil Plus Aplicap | 5.8±3.0 | E |
| Troconis et al. | PA+Prime & Bond NT®+ Filtek™ Z350 Flowable | 37.96±7.15 | A |
| | Clearfil™ SE Bond+ Filtek™ Z350 Flowable | 35.63±5.23 | B |
| | Adper™ Easy One+ Filtek™ Z350 Flowable | 34.90±8.33 | B |
| | Dyad™ Flow® | 32.66±8.20 | B |
| Troconis et al. | Clearfil™ SE Bond+Clearfil™ Majesty Flow | 14.70±2.47 | A |
| | Adper™ Easy One +Filtek™ Ultimate Flow | 12.90±2.40 | B |
| | All-Bond SE® +Aelite™ Flo | 8.29±2.66 | C |
| | Vertise Flow® | 2.94±1.95 | D |

Continue...
| Study            | Adhesive system | 1st mix | 2nd mix | 3rd mix | 4th mix | 5th mix | 6th mix | 7th mix |
|------------------|-----------------|---------|---------|---------|---------|---------|---------|---------|
| Primary teeth    |                 |         |         |         |         |         |         |         |
| Pacifi (2013)    | Optibond™ All-In-One + Premise™ Flowable | 16.59±1.77 | A | 16.02±3.15 | A | 6.04±3.76 | B | 5.91±4.80 | B | 4.31±2.66 | B | 4.3±1.6 | A |
| Tuloglu (2014)   | Optibond™ All-In-One + Filtek™ Ultimate Flowable | 15.6±2.6 | A | 8.7±1.7 | B | 4.1±2.3 | C |         |     |         |     |         |     |
| Sachdeva (2016)  | Adhesive system (NR) + G-aeniab Universal Flo® | 21.11±1.168 | A | 14.15±1.168 | B | 12.03±1.168 | B |         |     |         |     |         |     |
| Memarpour (2016) | OptiBond™ All-In-One+Premise™ Flowable | SIC:17.41±1.20 / Er:YAG laser:17.65±1.25 | A/A | SIC:16.89±1.05 / Er:YAG laser:13.93±0.97 | A/B | SIC:12.17±1.31 / Er:YAG laser:12.09±1.26 | B/C |         |     |         |     |         |     |
| Poorzandpoush (2019) | OptiBond™+ Premise™ Flowable | 15.5±10.06 | A | 13.0±6.99 | A | 2.3±2.93 | B |         |     |         |     |         |     |

Different capital letters mean statistically significant difference (p≤0.05) among study groups, reported on individual studies.

SiC: silicon carbide sandpaper; PolyA: Polyacrilic Acid; PA: Phosphoric acid; TC: thermocycling; NR: Not Reported; Er:YAG laser: erbium:yttrium aluminum garnet laser. Δ Vertise® Flow is marketed as Dyad™ Flow in some countries.
Discussion

According to our knowledge, this is the first systematic review that critically approaches the bonding performance of SAFRCs on permanent and primary teeth, comparing the outcomes with CFRCs associated to different adhesive systems. There were considerable variations in enamel bond strength values among included studies, probably due to methodological divergences such as type of teeth, specimen preparation technique, bonding test, enamel treatment, bonding area and load speed which made it impossible to conduct a meta-analysis. The results of this systematic review revealed low enamel bond strength of SAFRCs (Table 3), which was in agreement with previous studies testing the same SAFRCs or self-etching sealants exhibiting similar chemical composition. These findings may be explained due to enamel is a very complex and mineralized dental structure, which requires a surface treatment prior to composite resin restorations or resin-based sealant placement. Phosphoric acid etching is the most used strategy to promote micro morphological alterations on enamel surface, leading to an effective resin interlocking and enhanced bond strength. Some included studies revealed that SAFRCs applied under etched enamel exhibited higher bond strength values compared to SAFRCs used in self-etch mode. However, only two studies aimed to compare the findings between resin-based sealants and SAFRCs, highlighting the need for future research using this approach to confirm if SAFRCs applied on etched enamel could show the same bonding performance than resin-based sealants. Functional monomers such as GPDM and 4-META incorporated into Vertise® Flow and Fusio™ Liquid Dentin, respectively, are highly acidic but do not promote the same enamel demineralization pattern that phosphoric acid etching. Therefore, the bonding effectiveness of these functional monomers relies largely on the chemical interaction with dental HAp, which is lower and less stable compared to that promoted by 10-MDP monomer. These facts may explain why Vertise® Flow and Fusio™ Liquid Dentin used without prior phosphoric acid etching performed significantly worse than CFRCs.

Other strategies to improve the bonding effectiveness of adhesive restorations involve lasers such as erbium:yttrium aluminum garnet laser (Er:YAG) or neodymium-doped yttrium aluminum garnet (Nd:YAG). This was confirmed in one included study using Er:YAG laser (120 mJ, 10 Hz, 1.20 W) at 1 mm of distance from primary enamel. The results demonstrated that the bond strength of Vertise® Flow increased up to 38% following laser irradiation compared to SiC treatment, being comparable to bond strength values in control group (OptiBond™ All-In-One and Premise™ Flowable). The authors argued that the ablation effect promoted by Er:YAG laser on enamel surface resulted in a more irregular and micoretentive morphological pattern, increasing surface area for micromechanical interlocking of flowable resin composites, as reported in other micromorphological studies. Despite Er:YAG laser treatment increased the enamel bond strength of tested SAFRC, high cost and learning curve to manipulate the device makes it an unfeasible option compared to phosphoric acid etching.

Regarding dentin bond strength of SAFRCs, considerable mean variations were also found among included studies, probably due to the same reasons explained for enamel bonding tests. SAFRCs exhibited statistically lower dentin bond strength in contrast to CFRCs (Table 4) as well as predominant adhesive fail-
This indicates a deficient and non-stable chemical interaction between functional monomers incorporated into SAFRCs and dentin microstructure. These hypotheses were also demonstrated by a chemical study as well as on Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM) studies assessing Vertise® Flow. This self-adhesive flowable resin composite followed by Fusio™ Liquid Dentin were the most evaluated materials, especially in primary and permanent dentin, showing similar bond strength values. In contrast to GPDM and 4-META monomers, 10-MDP monomer promotes a superficial demineralization of dentin collagen fibers and enables a stable ionic interaction between phosphate group and remaining calcium ions of HAp, leading to satisfactory dentin bonding performance as demonstrated in other dental materials. Nonetheless, two included articles tested Constic®, a 10-MDP containing SAFRCs which revealed deficient dentin bond strength values, being comparable or lower than other SAFRCs that do not incorporate this phosphate monomer. This raises the suggestion that 10-MDP monomer by itself did not guarantee acceptable bonding performance of this SAFRC. There are other material-dependent factors such as water content, purity and functional monomer concentration which may negatively impact the bond strength of self-adhesive dental materials.

Self-adhesive resin cements and SAFRCs are flowable materials that present similar chemical composition. Self-adhesive resin cements also incorporate silanized inorganic fillers, methacrylate monomers and an activator-initiator system. In addition, self-adhesive resin cements contain functional monomers such as 10-MDP, 4-META, Dipentaerythritol penta-acrylate monophosphate (Penta-P) or others. One study included in this systematic review additionally compared the bond strength of Vertise® Flow and some self-adhesive resin cements, showing similar bonding performance to dentin. However, it is not possible to indicate SAFRCs as alternatives for metallic crowns, posts, inlays, onlays, or ceramic crowns cementation because dual-cured luting materials are desired for these clinical applications. SAFRCs are not even recommended as light-cured resin cements because film thickness is not suitable for that purpose and limited color availability. Besides bond strength of SAFRCs to hard dental tissues, other relevant aspects such as color stability, water sorption, solubility, nanoleakage, microleakage, polymerization stress, gap formation need further research.

Main strengths of this systematic review were extensive searches on different databases, strict selection criteria, risk of bias assessment and data extraction. Conversely, one limitation was that most included studies evaluated the immediate bond strength of SAFRCs to hard dental tissues. This is not clinically relevant due to mechanical loading, chemical and hydrolytic degradation of laboratorial samples are important issues to predict the possible mechanical performance of adhesive restorations. In addition, the findings should be carefully interpreted due to most included evidence showing medium risk of bias (table 2) which appears to be usual in systematic reviews of in vitro studies on dental adhesion. The lack of methodological homogeneity was another limitation that made it impossible to conduct a meta-analysis. Based on the results of the current systematic review, it is possible to affirm that chemical changes on SAFRCs as well as additional studies are required to consider...
these dental materials as a possible alternative in restorative and preventive dentistry. For a while, the use of phosphoric acid on enamel is essential on resin-based sealants placement. Also, the acid etching, especially in enamel and adhesive systems in both hard dental tissues remains as mandatory steps for successful restorative treatments involving resin composites.

Self-adhesive flowable resin composites, such as Vertise® Flow and Fusio™ Liquid Dentin used in self-etch mode exhibited lower bond strength to enamel and dentin from permanent teeth, compared to conventional flowable resin composites. The bonding performance of Constic® on both hard dental tissues should be evaluated on future studies. The evidence is still limited to support that self-adhesive flowable resin composites applied under etched enamel exhibit comparable bond strength to resin-based sealants. The number of studies assessing the bond strength of self-adhesive flowable resin composites to primary teeth are limited.

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