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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 vitro* 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-analysis)[17]. 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-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 ($p \leq 0.05$) 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 adhesion[18-19]. 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.

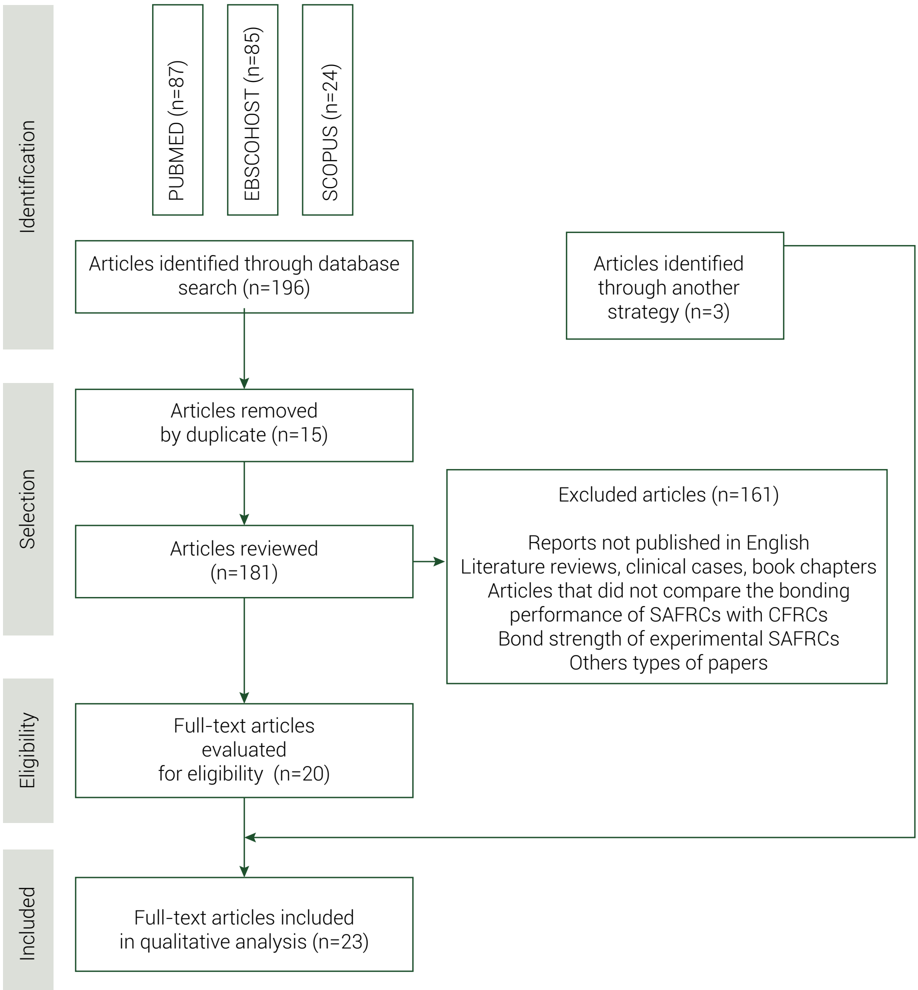

Figure 1. Selection process, according to PRISMA guidelines.

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)[8,9,16,20-39] 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[16,22,26,30,34,38]. 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[29,35,37]. The bond strength of SAFRCs was mainly assessed by shear bonding test (n=20)[8,16,20-27,29-33,35-39] and tensile bonding test (n=3)[9,28,34], 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)[26,29,33,35,36,38]. 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[8,9,20-24,27-39].

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)[8]	Enamel (n=50) Dentin (n=50)	Permanent molars	PA + OptiBond™ FL + Premise ™ flowable OptiBond™ XTR + Premise™ flowable PA + OptiBond™ XTR + Premise™ flowable Vertise Flow® PA + Vertise Flow®	ERAs + CFRC 2S-SEAs+CFRC 2S-SEAs+CFRC SAFRC SAFRC	Enamel and dentin	SBS	Not / NA	3mm in diameter / 0.5mm/ min	Stereomicroscope	AF
Wajdowicz (2012)[20]	NR	Third molars	Vertise Flow® Fusio™ Liquid Dentin PA + Optibond™ FL + Vertise Flow® PA + Optibond™ FL + Fusio™ Liquid Dentin PA + Optibond™ FL + Revolution™	SAFRC SAFRC ERAs+SAFRC ERAs+SAFRC ERAs+CFRC	Enamel	SBS	Not / NA	2.4mm in diameter / 1mm/min	Stereomicroscope	AF in Fusio™ Liquid Dentin
Vichi A (2013)[21]	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 1S-SEAs+CFRC 1S-SEAs+CFRC 1S-SEAs+CFRC 1S-SEAs+CFRC SAFRC	Enamel and dentin	SBS	Not / NA	3mm in diameter / 0.5mm/ min	Optical microscope	AF
Pacifici E (2013)[22]	50	Primary molars	Optibond™ All-In-One+Premise ™ Flow PA +Optibond™ FL+Premise ™ Flow PolyA+Fuji II® PolyA+Fuji IX® Vertise Flow®	1S-SEAs+CFRC ERAs+CFRC Glass ionomer Glass ionomer SAFRC	Dentin	SBS	Not / NA	3mm in diameter / 1mm/min	Stereomicroscope	AF
Yazici AR (2013)[23]	80	Permanent molars	PA+Optibond™ Solo Plus+Premise™ Flow Vertise Flow®	ERAs+CFRC SAFRC	Dentin	SBS	Not / NA	2.38mm in diameter / 1mm/min	Optical microscope	AF
Margvelashvili M, (2013)[24]	30	Permanent molars	PA + Vertise Flow® PA + Guardian Seal® Adper™ Prompt L-Pop + Clinpro™ Sealant	SAFRC CFRC 1S-SEAs+ CFRC	Enamel	SBS	Not / NA	3mm in diameter / 0.5mm/min	Optical microscope SEM	AF
Bektas OO (2013)[25]	30	Third molars	Optibond™ All-In-One + Revolution™ Formula2 Vertise Flow® Optibond™ All-In-One + Vertise Flow®	1S-SEAs+CFRC SAFRC 1S-SEAs+SAFRC	Dentin	µSBS	Not / NA	0.7mm in diameter / 1mm/min	NA	NA

Continue...

Table 1. Continuation.

Poitevin A (2013)[9]	Enamel (n=40) Dentin (n=55)	Third molars	Fusio™ Liquid Dentin Vertise Flow® PA + Vertise Flow® Adhese One® + Tetric Evo flow® Adper™ Prompt L-Pop +Filtek™ Supreme XT Flowable iBond® + Venus Flow® Xeno® V + X flow® PA+OptiBond™ FL + Premise ™ flowable	SAFRC SAFRC SAFRC 1S-SEAs+CFRC 1S-SEAs+CFRC 1S-SEAs+CFRC 1S-SEAs+CFRC ERAs+CFRC	Enamel and dentin	μTBS	Not / NA	1mm in diameter / 1mm/min	Stereomicroscope Feg-SEM	AF
Tuloglu N (2014)[26]	60	30 primary molars 30 permanent molars	Vertise Flow® Optibond™ All-In-One + Filtek™ Ultimate Flowable Optibond™ All-In-One + Vertise Flow®	SAFRC 1S-SEAs+CFRC 1S-SEAs+SAFRC	Dentin	SBS	TC 500 cycles (between 5°C and 55°C for 10s)	2mm in diameter / 1mm/min	NA	NA
Russo D (2014)[27]	72	Permanent molars	PA+Optibond™ FL + Premise™ Flowable Optibond™ XTR + Premise ™ Flowable Vertise Flow® Smart Cem2® RelyX™ Unicem 2 SpeedCem® MaxCem Elite™ RelyX™ Unicem Ketac™Conditioner Refill + Ketac™ Fil Plus Aplicap	ERAs+CFRC 2S-SEAs+CFRC SAFRC SARC SARC SARC SARC SARC SAGIC	Dentin	μSBS	Not / NA	0.95-1.45mm in diameter / 1mm/min	SEM	AF
Yuan H (2015)[28]	40	Third molars	Adper™ Easy One + Filtek™ Z350 Flowable Clearfil™ SE Bond+ Filtek™ Z350 Flowable PA+Prime & Bond NT®+ Filtek™ Z350 Flowable Dyad™ Flow$^{\Delta}$	1S-SEAs+CFRC 2S-SEAs+CFRC ERAs+CFRC SAFRC	Dentin	μTBS	Not / NA	1mm in diameter / 0.5mm/min	Stereomicroscope SEM	AF
Schuldt (2015)[29]	90	Third molars	Constic® PA + Constic® PA + Helioseal F®	SAFRC SAFRC CFRC	Enamel	SBS	TC 5000 cycles (between 5°C and 55°C)	2.38 in diameter / 1mm/min	Stereomicroscope	AF

Continue...

Table 1. Continuation.

Sachdeva P (2016)[16]	60	Primary teeth	Dyad™ Flow$^{\Delta}$ 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)[30]	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 SEM	AF and MF.
Almaz M, (2016)[31]	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-SEAs+CFRC 1S-SEAs+CFRC	Dentin	SBS	Not / NA	3mm in diameter / NR	Iluminated microscope	AF
Moslemi (2016)[32]	40	Third molars	SiC + Er,Cr:YSGG laser + Single-Bond® + CFRC(NR) SiC+ Er,Cr:YSGG laser + Dyad™ Flow$^{\Delta}$ SiC + Single-Bond® + CFRC (NR) SiC + Dyad™ Flow$^{\Delta}$	ERAs+CFRC SAFRC ERAs+CFRC SAFRC	Dentin	μSBS	Not / NA	0.7mm in diameter / 0.5mm/min	Stereomicroscope	AF in SAFRCs without laser.
Bumrungruan (2016)[33]	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
Durmuşlar S (2017)[34]	60	Primary molars	Vertise Flow® G-aenial Bond® + G-aenial Universal Flo® PA+ Tetric® N-Bond+ Tetric® N-Flow	SAFRC 1S-SEAs+CFRC ERAs+CFRC	Dentin	μTBS	Not / NA	3mm in diameter / 1mm/min	SEM	AF
Peterson J (2017)[35]	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	Enamel and dentin	SBS	TC (5000 cycles (between 5°C and 55°C)	3mm in diameter / 1mm/min	Stereomicroscope	AF
Brueckner C (2017)[36]	Enamel (n=80) Dentin (n=80)	Permanent molars	Vertise Flow® Fusio™ Liquid Dentin Adper™ Prompt L-Pop + Filtek™ Supreme XT flowable	SAFRC SAFRC 1S-SEAs+CFRC	Enamel and dentin	SBS	TC (1500 cycles (between 5°C and 55°C)	3mm in diameter / 0.75 ± 0.25 mm/min	SEM	AF

Continue...

Table 1. Continuation.

Rangappa A (2018)[37]	64	Permanent molars	Constic® Dyad™ Flow$^{\Delta}$ PA+ Tetric® N-Bond+ Tetric® N-Flow	SAFRC SAFRC ERAs+CFRC	Dentin	SBS	Not / NA	3mm in diameter / 1mm/min	SEM	AF
Poorzandpoush (2019)[38]	48	Primary canines and first molars	PA+ 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)[39]	Enamel (n=24) Dentin (n=12)	Permanent molars	Dyad™ Flow$^{\Delta}$ PA+ Universal Single Bond®+ Filtek™ Z350-XT	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: Polyacrilic 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), G-Bond™ (GC, Tokyo, Japan), Gradia® Direct LoFlo (GC, Tokyo, Japan), AdhSE One® (Ivoclar Vivadent, Schaan, Liechtenstein), Tetric® Evo Flow (Ivoclar Vivadent, Schaan, Liechtenstein), Revolution™ Formula2 (Kerr, Orange, CA, USA), iBond® (Heraeus Kulzer, Hanau, Germany), Optibond™ All in one (Kerr, Orange, CA, USA), Fuji II® (GC, Tokyo, Japan), Fuji® IX (GC, Tokyo, Japan), Optibond™ Solo Plus (Kerr, Orange, CA, USA), Guardian Seal® (Kerr, Orange, CA, USA), Adper™ Prompt L-Pop (3M ESPE, St. Paul, MN, USA), Clinpro™ Sealant (3M ESPE, St. Paul, MN USA), Filtek™ Ultimate Flowable (3M ESPE, St. Paul, MN, USA), Adper™ Easy One (3M ESPE, St. Paul, MN, USA), Filtek™ Z350 Flowable (3M ESPE, St. Paul, MN, USA), Smart Cem2®(Dentsply, York, PA, USA), RelyX™ Unicem 2(3M ESPE, Germany), SpeedCem®(Ivoclar Vivadent, Schaan, Liechtenstein), MaxCem Elite™ (Kerr, Orange, CA, USA), RelyX™ Unicem(3M ESPE, Germany), Ketac™Conditioner Refill(3M ESPE, Germany), Ketac™ Fil Plus Aplicap(3M ESPE, Germany), Clearfil™ SE Bond (Kuraray, Okayama, Japan), Prime & Bond NT® (Dentsply, York, PA, USA), Constic® (DMG, Hamburg, Germany), Helioseal F® (Ivoclar Vivadent, Schaan, Liechtenstein), G-aenial™ Universal Flo (GC, Tokyo, Japan), Clearfil™ Majesty Flow (Kuraray, Okayama, Japan), 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), Tetric® N-Bond (Ivoclar Vivadent, Schaan, Liechtenstein), Tetric® N-Flow (Ivoclar Vivadent, Schaan, Liechtenstein), Venus Diamond Flow® (Heraeus Kulzer, Hanau, Germany); 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[35] to 15.3 Mpa[9]), Fusio™ Liquid Dentin (from 3.0[35] to 13.0 MPa[9]) and Constic® (from 3.9[29] to 4.5 MPa[35]). Overall, mean bond strength of SAFRCs to previously etched enamel varied from 9.87[8] to 23.1 MPa[9]. Conversely, the mean enamel bond strength of CFRCs associated with different types of adhesive systems ranged between 5.0[21] and 28.0 MPa[9] 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[30]. 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[35] to 32.66 MPa[28]), Fusio™ Liquid Dentin (from 2.8[35] to 17.7 MPa[9]) and Constic® (from 0.8[35] and 12.2 MPa[37]). Overall, the bond strength of SAFRCs used on previously etched dentin or associated to an adhesive system ranged between 5.48[8] and 35.08 MPa[25]. Two studies employed thermocycling[33,36] and the results revealed that bond strength of Fusio™ Liquid Dentin decreased from 4.4 MPa to 1.6 MPa[36] following thermocycling while the values for Vertise® Flow diminished from 3.0 to 1.0 MPa[36] and from 22.1 to 21.1 MPa[33]. Six studies evaluated the bonding performance of SAFRCs to primary teeth[16,22,26,30,34,38] without prior acid etching or adhesive system use. The mean dentin bond strength values were: Vertise® Flow (from 2.3[34] to 12.17 MPa[30]) and Fusio™ Liquid Dentin (14.15 MPa[16]). Two studies[26,30] evaluated the dentin bond strength of Vertise® Flow associated to Optibond™ All-In-One adhesive system and mean bond strength ranged between 8.7[26] and 16.89 MPa[30]. On the other hand, mean bond strength of CFRCs associated to different adhesive systems varied from 14.87[38] to 21.11 MPa[16]. 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 al[8]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Wajdowicz et al[20]	No	No	Yes	Yes	Yes	Yes	No	No	Medium
Vichi et al[21]	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Low
Pacifici et al[22]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Yazici et al[23]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Margvelashvili et al[24]	Yes	No	Yes	No	Yes	Yes	Yes	No	Medium
Bektas et al[25]	Yes	No	Yes	Yes	No	Yes	No	No	Medium
Poitevin et al[9]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Tuloglu et al[26]	Yes	No	Yes	No	No	Yes	No	No	High
Russo et al[27]	Yes	No	Yes	Yes	Yes	No	No	No	Medium
Yuan et al[28]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Schuldt et al[29]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Sachdeva et al[16]	Yes	No	Yes	Yes	No	Yes	No	No	Medium
Memarpour et al[30]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Almaz et al[31]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Moslemi et al[32]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Bumrungruan et al[33]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Durmuşlar et al[34]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Peterson et al[35]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Brueckner et al[36]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Rangappa et al[37]	Yes	No	Yes	Yes	Yes	Yes	No	No	Medium
Poorzandpoush et al[38]	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Low
Abdelraouf et al[39]	Yes	No	Yes	Yes	Yes	Yes	No	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 Mean ± Standard deviation	Significant difference
Permanent teeth			
Juloski (2012)[8]	PA + OptiBond™ FL + Premise ™ flowable PA + Vertise Flow® OptiBond™ XTR + Premise™ flowable. PA + OptiBond™ XTR + Premise™ flowable Vertise Flow®	16.83±2.93 9.87±4.24 8.59±4.39 7.04±3.63 6.61±2.41	A B B B B
Wajdowicz (2012)[20]	PA + Optibond™ FL + Vertise Flow® PA + Optibond™ FL + Fusio™ Liquid Dentin PA + Optibond™ FL + Revolution™ Fusio™ Liquid Dentin Vertise Flow®	10.2±NR 8.5±NR 8.3±NR 3.6±NR 3.5±NR	A A A B B
Vichi A (2013)[21]	EasyBond + Filtek™ Supreme XT Flow Xeno® V + X Flow® G-Bond™ + Gradia® Direct LoFlo AdheSE One + Tetric Evo Flow® iBond® + Venus Flow® Vertise Flow®	12.1±5.0 10.4±4.0 7.7±1.9 6.0±4.0 5.0±1.8 2.6±2.6	A AB ABC BCD CD D
Margvelashvili (2013)[24]	PA + Vertise Flow® Adper™ Prompt L-Pop + Clinpro™ Sealant PA + Guardian Seal	17.9±2.9 12.9±6.0 11.7±4.6	A AB B
Poitevin (2013)[9]	Adper™ Prompt L-Pop + Filtek™ Supreme XT Flowable PA + Vertise Flow® Fusio™ Liquid Dentin Vertise Flow®	Bur-cut:28.0±9.8/SiC-Ground:25.5±8.2 Bur-cut:23.1±7.1/SiC-Ground:22.6±7.6 Bur-cut:13.0±4.3/SiC-Ground:10.8±5.8 Bur-cut:11.0±4.2/SiC-Ground:15.3±6.0	A/A A/A B/B B/B
Schuldt (2015)[29]	PA + Helioseal F® PA + Constic® Constic®	19.1±6.2 / TC:15.6±4.4 17.1±5.1 / TC:13.0±3.8 4.3±1.6 / TC:3.9±1.4	A/A A/AB C/C
Peterson (2017)[35]	PA+Optibond™ FL + Venus Diamond Flow® Constic® Fusio™ Liquid Dentin Vertise Flow®	13.0±5.1 4.5±NR 3.0±NR 2.0±NR	A B B B
Brueckner (2017)[36]	Adper™ prompt L-pop + Filtek™ Supreme XT Flowable Experimental flowable Vertise Flow® Fusio™ Liquid Dentin	9.8±3.6 /TC: 8.3±3.7 4.4±3.0 / TC: 0.7±0.4 4.0±2.1 / TC: 0.4±0.4 3.5±2.3 / TC: 0.5±0.1	A/A B/B B/BC C/C
Abdelraouf (2019)[39]	PA+ Universal Single Bond®+ Filtek™ Z350-XT Dyad™ Flow$^{\Delta}$	Uncut: 24.6±6.2/ Cut: 12.7±4.5 Uncut: 3.5±1.6/ Cut: 4.5±2.7	A/B C/C
Primary teeth			
Memarpour (2016)[30]	OptiBond™ All-In-One+Vertise Flow® OptiBond™ All-In-One+Premise™ Flowable Vertise Flow®	SiC:15.05±2.12 / Er:YAG laser:16.16±3.16 SiC:13.06±2.36 / Er:YAG laser:13.90±2.76 SiC:9.29±1.56 / Er:YAG laser:14.84±1.32	A/A A/A 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. ΔVertise® Flow is marketede as Dyad™ Flow in some countries.

Table 4. Means, standard deviations and statistically significant differences on dentin bond strength between SAFRCs and CFRCs.

Permanent teeth			
Author (year)	**Materials**	**Dentin Bond Strength in MPa Mean ± Standard deviation**	**Significant difference**
Juloski (2012)[8]	OptiBond™ XTR + Premise™ flowable. PA + OptiBond™ XTR + Premise™ flowable PA + OptiBond™ FL + Premise ™ flowable PA + Vertise Flow® Vertise Flow®	10.60±5.0 9.60±4.91 8.15±3.88 5.48±4.94 2.94±2.79	A A AB BC C
Vichi A (2013)[21]	EasyBond + Filtek™ Supreme XT Flow AdheSE One + Tetric Evo Flow Xeno® V + X Flow G-Bond™ + Gradia® Direct LoFlo iBond® + Venus Flow® Vertise Flow®	12.2±3.6 11.3±5.7 10.7±4.7 6.9±3.2 5.8±1.2 3.4±1.6	A A A AB AB B
Yazici (2013)[23]	PA+ Optibond™ Solo Plus + Premise™ Flow Vertise Flow®	SiC:14.64±6.75 / Er:YAG laser:16.81±6.76 SiC:7.92±2.91 / Er:YAG laser:12.61±3.49	A/A B/A
Bektas (2013)[25]	Optibond™ All-In-One/Vertise flow® Optibond™ All-in-one/ Revolution™ Formula2 Vertise Flow®	35.08±7.0 29.33±5.19 23.70±5.28	A B C
Poitevin (2013)[9]	PA+Optibond™ FL + Premise™ Flowable Xeno® V + X-Flow® Adper™ Prompt L-Pop + Filtek™ Supreme XT Flowable iBond® + Venus Flow® PA + Vertise Flow® Fusio™ Liquid Dentin AdheSe One® + Tetric EvoFlow® Vertise Flow®	Bur-cut:44.8±13.6/SiC-Ground:NR Bur-cut:29.4±11.7/SiC-Ground:NR Bur-cut:25.4±10.0/SiC-Ground:34.9±13.4 Bur-cut:23.9±10.3/SiC-Ground:NR Bur-cut:18.7±11.0/SiC-Ground:NR Bur-cut:17.7±8.6/SiC-Ground:17.19.5 Bur-cut:7.9±5.3/SiC-Ground:NR Bur-cut:1.8±2.7 /SiC-Ground:5.36.7	A/NR A/NR A/A B/NR B/NR B/B C/NR C/C
Tuloglu (2014)[26]	Optibond™ All-In-One + Filtek™ Ultimate Flowable Optibond™ All-In-One + Vertise Flow® Vertise Flow®	35.7±2.9 25.6±3.0 19.3±2.3	A B C
Russo (2014)[27]	OptiBond™ XTR + Premise™ Flowable PA+ Optibond™ FL + Premise™ Flowable Smart Cem2® RelyX™ Unicem 2 SpeedCem® MaxCem Elite™ Vertise Flow® RelyX™ Unicem Ketac™ Fil Plus Aplicap	25.3±13.0 20.8±7.8 11.6±6.9 11.3±7.3 10.7±5.5 9.6±5.3 7.1±4.0 6.3±3.2 5.8±3.0	A A B BC BCD BCDE CDE DE E
Yuan H (2015)[28]	PA+Prime & Bond NT®+ Filtek™ Z350 Flowable Clearfil™ SE Bond+ Filtek™ Z350 Flowable Adper™ Easy One+ Filtek™ Z350 Flowable Dyad™ Flow$^{\Delta}$	37.96±7.15 35.63±5.23 34.90±8.33 32.66±8.20	A B B C
Almaz (2016)[31]	Clearfil™ SE Bond+Clearfil™ Majesty Flow Adper™ Easy One +Filtek™ Ultimate Flow All-Bond SE® +Aelite™ Flo Vertise Flow®	14.70±2.47 12.90±2.40 8.29±2.66 2.94±1.95	A B C D

Continue...

Table 4. Continuation.

Moslemi (2016)[32]	SiC + Er,Cr:YSGG laser+PA+Single-Bond®+ CFRC (NR) SiC + PA+Single Bond® + CFRC (NR) SiC+ Er,Cr:YSGG laser + Dyad™ Flow$^{\Delta}$ SiC + Dyad™ Flow$^{\Delta}$	20.62±0.125 19.72±0.01 16.42±0.01 12.85±0.01	A A A B
Bumrungruan (2016)[33]	PA+OptiBond™ FL+ Premise™ Flowable OptiBond™ All-In-One+ Premise™ Flowable Vertise Flow®	32.2±8.94 / TC: 31.8±6.80 24.4±6.21 / TC: 23.9±7.14 22.1±6.13 / TC: 21.1±5.39	A/A B/B B/B
Peterson (2017)[35]	PA+Optibond™ FL + Venus Diamond Flow® Fusio™ Liquid Dentin Vertise Flow® Constic®	11.2±6.3 2.8±NR 1.0±NR 0.8±NR	A B B B
Brueckner (2017)[36]	Adper™ Prompt L-Pop + Filtek™ Supreme XT Flowable Fusio™ Liquid Dentin Vertise Flow® Self-adhesive experimental flowable	11.6±3.5 / TC:5.4±3.7 4.4±1.3 / TC:1.6±2.1 3.0±2.6 / TC:1.0±1.6 2.4±4.1 / TC:0.7±0.0	A/A B/B B/B B/B
Rangappa A (2018)[37]	PA+ Tetric® N-Bond+ Tetric® N-Flow Dyad™ Flow$^{\Delta}$ Constic®	Carbide bur:23.0±3.1 /Diamond bur:18.2±2.6 Carbide bur:14.6±2.1 /Diamond bur:11.9±1.7 Carbide bur:12.2±3.1 /Diamond bur:10.2±2.7	A/A B/B C/C
Abdelraouf (2019)[39]	PA+ Universal Single Bond®+ Filtek™ Z350-XT Dyad™ Flow$^{\Delta}$	6.7±1.7 4.3±1.6	A B
Primary teeth			
Pacifici (2013)[22]	Optibond™ All-In-One + Premise™ Flowable PA + Optibond™ FL + Premise™ Flowable PolyA + Fuji IX® PolyA + Fuji II® Vertise Flow®	16.59±1.77 16.02±3.15 6.04±3.76 5.91±4.80 4.31±2.66	A A B B B
Tuloglu (2014)[26]	Optibond™ All-In-One + Filtek™ Ultimate Flowable Optibond™ All-In-One + Vertise Flow® Vertise Flow®	15.6±2.6 8.7±1.7 4.1±2.3	A B C
Sachdeva (2016)[16]	Adhesive system (NR) +G-aenial Universal Flo® Fusio™ Liquid Dentin Dyad™ Flow$^{\Delta}$	21.11±1.168 14.15±1.168 12.03±1.168	A B B
Memarpour (2016)[30]	OptiBond™ All-In-One+Premise™ Flowable OptiBond™ All-In-One+Vertise Flow® Vertise Flow®	SiC:17.41±1.20 / Er:YAG laser:17.65±1.25 SiC:16.89±1.05 / Er:YAG laser:13.93±0.97 SiC:12.17±1.31 / Er:YAG laser:12.09±1.26	A/A A/B B/C
Durmuşlar S (2017)[34]	G-aenial Bond® + G-aenial Universal Flo® PA+ Tetric® N-Bond+ Tetric® N-Flow Vertise Flow®	15.5±10.06 13.0±6.99 2.3±2.93	A A B
Poorzandpoush (2019)[38]	PA+ OptiBond™+ Premise™ Flowable Vertise Flow®	14.87±3.42 6.60±1.97	A 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[40,41] or self-etching sealants exhibiting similar chemical composition[42,43]. These findings may be explained due to enamel is a very complex and mineralized dental structure[44], 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[45,46]. Some included studies revealed that SAFRCs applied under etched enamel exhibited higher bond strength values compared to SAFRCs used in self-etch mode[9,29]. However, only two studies aimed to compare the findings between resin-based sealants and SAFRCs[24,29], 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[47]. 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[48]. These facts may explain why Vertise® Flow and Fusio™ Liquid Dentin used without prior phosphoric acid etching performed significantly worse than CFRCs[8,9,20,21,30,36]

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)[49,50]. This was confirmed in one included study[30] 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 microretentive morphological pattern, increasing surface area for micromechanical interlocking of flowable resin composites[30], as reported in other micromorphological studies[51,52]. 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)[8,9,16,21-23,25-28,30-32,34-39] as well as predominant adhesive failures[8,9,22,23,28,30,31,33,34-39]. 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[48] as well as on Transmission Electron Microscopy (TEM)[53] and Scanning Electron Microscopy (SEM) studies assessing Vertise® Flow[54]. 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[16,35,36]. 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[55], leading to satisfactory dentin bonding performance as demonstrated in other dental materials[56,57]. Nonetheless, two included articles[35,37] tested Constic®, a 10-MDP containing SAFRCs which revealed deficient dentin bond strength values, being comparable[35] or lower[37] 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[58,59].

Self-adhesive resin cements[60] 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[60]. One study[27] 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[60]. SAFRCs are not even recommended as light-cured resin cements because film thickness is not suitable for that purpose and limited color availability[5]. Besides bond strength of SAFRCs to hard dental tissues, other relevant aspects such as color stability[61], water sorption, solubility[13], nanoleakage[14], microleakage[16,62], polymerization stress, gap formation[63] 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[18,19]. 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[8,9,20-23,26,27,28,31,33,36,37].

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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