Frontiers in Dentistry

The Effect of Finishing and Polishing Systems on Surface Roughness and Microbial Adhesion of Bulk Fill Composites: A Systematic Review and Meta-analysis

Hoda Saleh Ismail*, Ashraf Ibrahim Ali

Conservative Dentistry Department, Faculty of Dentistry, Mansoura University, Mansoura, Egypt.

Article Info

Article type:
Systematic Review

Article History:
Received: 28 May 2022
Accepted: 10 Nov 2022
Published: 26 Jul 2023

*** Corresponding author:***
Conservative Dentistry Department, Faculty of Dentistry, Mansoura University, Egypt
Email: hoda_saleh@mans.edu.eg

A B S T R A C T

Objectives: This paper presents a systematic review and meta-analysis of the effect of different finishing and polishing (F/P) systems on surface roughness (SR) and microbial adhesion to bulk fill (BF) composites.

Materials and Methods: An electronic search of 3 databases (the National Library of Medicine [MEDLINE/PubMed], Scopus, and ScienceDirect) was conducted. Only in vitro studies that evaluated SR and microbial adhesion to BF composites were included. The included studies were individually evaluated for the risk of bias following predetermined criteria. A meta-analysis of the reviewed studies was conducted to compare the SR values of both Filtek Bulk Fill and Tetric EvoCeram Bulk Fill with and without F/P using the Comprehensive Meta-Analysis software.

Results: A total of 12 studies fulfilled the inclusion criteria. The meta-analysis showed no significant difference between Filtek Bulk Fill and Tetric EvoCeram Bulk Fill without F/P or after F/P using multi-step systems. Different F/P systems affected the SR values, on the other hand, did not affect microbial adhesion values.

Conclusion: Both Filtek Bulk Fill and Tetric EvoCeram Bulk Fill had comparable roughness results. Multi-step systems may be preferable for F/P of BF composites.

Keywords: Bacterial Adhesion; Composites; Dental Polishing; Systematic Review

➢ **Cite this article as:** Ismail HS, Ali AI. The Effect of Finishing and Polishing Systems on Surface Roughness and Microbial Adhesion of Bulk Fill Composites: A Systematic Review and Meta-analysis. *Front Dent*. 2023:20:26.

INTRODUCTION

The increasing demand for esthetic restorations has led to the rapid development of resin composites, in both filler particle and resin matrix compositions [1]. One such development includes Bulk fill (BF) composites. Bulk fill resin composites with different chemical compositions are designed to reduce polymerization shrinkage stress [2]. In addition, they can be placed in layers up to 4-mm thick and cured in one single step. This is due to the incorporation of polymerization modulators and increased translucency [1,2].

Bulk fill composites have been classified according to their viscosity into: low-viscosity BF composites (flowable, base) that generally have a lower filler content and are best used as a base or for small restorations, and high-viscosity BF composites (sculptable, full-body), that generally have higher filler content and can be used to cover the softer flowable BF composites or can be used to fill entire restorations [3,4].

After the placement of resin composite, proper finishing and polishing (F/P) procedures are mandatory to remove excess material and to create smooth highly polished restorations [5]. A perfectly smooth surface is a requirement for a desirable esthetic appearance [6]. In addition, a significant relationship between surface roughness and gloss of resin composites has been reported, and that may provide a better match with the surrounding tooth structure [3]. Furthermore, smooth surface can decrease the coefficient of friction leading to a reduced rate of wear [6]. Although many factors are involved in the outcome of the F/P procedures, differences in filler type, size and shape between different types of resin composites, can affect their polishability [7].

The presence of microbial biofilm is closely related to the development of secondary caries. Restoration surface properties, like surface roughness (SR), surface free energy (SFE) and hydrophobicity, have been reported to significantly affect microbial adhesion [8]. Therefore, apart from esthetic requirements, creating a smooth restoration surface can impair the plaque retention and colonization of microbial cells that may cause secondary caries, gingival inflammation and periodontal disease [9].

Even BF composites are mainly considered for posterior restorations, yet creating basic esthetic characteristics is still required. In addition, they became common restorative options for different clinical situations, including class V and deep subgingival class II cavities [10,11], where smooth restorations must be given further care and attention as gingiva healing is highly dependent on the restoration contour and smoothness [12].

The increasing demand for BF composites by clinicians has led to great commercial variety. In addition, there is a large variety of F/P systems available [13]. Although this variety provides multiple options for clinicians to use, it makes selecting for the best material and F/P system more challenging.

Although the effect of F/P on the roughness and microbial adhesion of conventional layered resin composites has been systematically investigated and demonstrated [14,15], there is a conflict of data regarding this topic for BF composites. Therefore, the aim of this review was to systematically review the literature to obtain information on the best potential category of BF composite and which F/P system to use with them regarding smoothness and microbial adhesion. To the authors' knowledge, this is the first research conducted to systematically analyze the current literature regarding this topic.

MATERIALS AND METHODS

PICO

With reference to problems (P), interventions (I), comparators (C), and outcomes (O), (PICO) [16], the research questions in this systematic review were, what category of BF composites (C) best produces the smoothest surfaces and less microbial adhesion (O) if the same F/P protocol (P) is used (I)? To answer also, what are the best F/P protocols (C) to use (I) to produce the least SR and microbial adhesion (O) for BF composites (P)?

Information source and systematic search

The review methodology was based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [17].

Three electronic databases were searched in this systematic review: National Library of Medicine (MEDLINE/PubMed), Scopus and ScienceDirect. The following keywords and medical subject headings (MeSH) were used to search these databases: "Surface roughness of restorative materials" OR "Microbial adhesion to restorative materials" OR "Bulk fill resin composite" OR "Sonic fill resin composite" OR "Finishing and polishing of restorative materials".

Resources that were not available on the internet were manually checked. Subsequently, the selected articles were imported to Endnote X7.7 software (Thompson Reuters, Philadelphia, PA, USA) to remove duplicates. A gray literature search was conducted following the online database search.

Search strategy

The articles were selected based on (1) the relevance of the title, (2) the relevance of the abstract and, (3) the analysis of the full text. Each author received a copy of the articles found by electronic search. The included studies should be in vitro studies that investigated the effect of different F/P protocols on SR and microbial adhesion to different categories of BF composites.

Assessment of risk of bias

The risk of bias was independently assessed by the two authors based on the parameters used by previous systematic reviews of laboratory studies [18,19]. If a parameter was reported to be used in the study, "yes" was assigned to that parameter. Whereas, if information was missing, or if a parameter was not reported, then this parameter was assigned "No".

Articles reporting 1 to 3 parameters were classified as having a high risk of bias. Those reporting 4 or 5 parameters were considered to have a medium risk of bias, and those reporting 6 or 7 parameters were classified as having a low risk of bias. The risk of bias graph and summary for the selected studies were obtained by RevMan 5.3.

Statistical analysis

Studies included in the meta-analysis should compare the quantitative roughness (Ra) values of nanofilled (Filtek Bulk Fill) and nanohybrid (Tetric EvoCeram Bulk fill) regular BF composites, either without any surface alteration (cured against Mylar) or following F/P with the same multi-step systems.

The sample size, the mean and the standard deviation SD (µm) were extracted from studies and subjected to a meta-analysis using Comprehensive Meta-Analysis software, version 3 (Biostat, Englewood, NJ, USA), with 95% confidence interval. Data heterogeneity was assessed using the Q homogeneity test with significance set at $P<0.05$.

RESULTS

Search results

Electronic searches, which were filtered to exclude any study prior to 2010, yielded 1,098 published articles. After removing duplicates and non-English articles, the titles/abstracts of the 951 search results were independently evaluated by the authors, and 821 studies were excluded for one (or more) of the following reasons: book sections, case reports and clinical trials, reviews, implant supported restorations, indirect restoration, not related to research question. 130 studies were assessed in full-text form for eligibility. Following the inclusion and exclusion criteria, 118 studies were excluded. Finally, 12 studies fulfilled the inclusion criteria originally specified for this review. The search stages are illustrated in the flowchart (Figure 1).

Data extraction

The current review evaluated 12 studies [20-31] conducted to evaluate the effect of different F/P protocols on SR and microbial adhesion to different categories of BF composites. All included studies evaluated SR while three of them evaluated microbial adhesion [20, 26, 30]. Extracted data from the studies are summarized in Table 1.

Bulk fill composites used

Different BF composites were used in the included studies. To facilitate the material selection assessment, the authors of this review categorized the BF composites used according to their viscosities into regular BF, flowable BF resin composite with sonic activation and flowable BF, and then further subdivided according to the size of fillers into nanofilled, nanohybrid or microhybrid. Scientific categories and brand names of all BF composites used in the included studies are presented in Table 2.

Finishing and polishing

Finishing and polishing systems

The different F/P systems evaluated in the included studies were classified as proposed by Jefferies et al. [32] to: trimming (fluted carbide) and abrading (diamond) burs; coated (discs) and bonded (rubber with different shapes) abrasives; abrasive impregnated brushes and liquid polisher. All details regarding F/P systems used in the included studies are presented in Table 3.

Finishing and polishing procedures

Wet F/P procedures were utilized in five studies [20,21,24,28,30]. In contrast, four studies performed dry F/P [23,25,26,31]. Two studies performed wet finishing and dry polishing [22,29]. Both wet and dry F/P, were performed with different systems in the same study [27]. Ten studies performed the F/P procedures immediately after specimen preparation [20-24,26,28-31], while two studies stored the specimens for 24 hours before F/P [25,27].

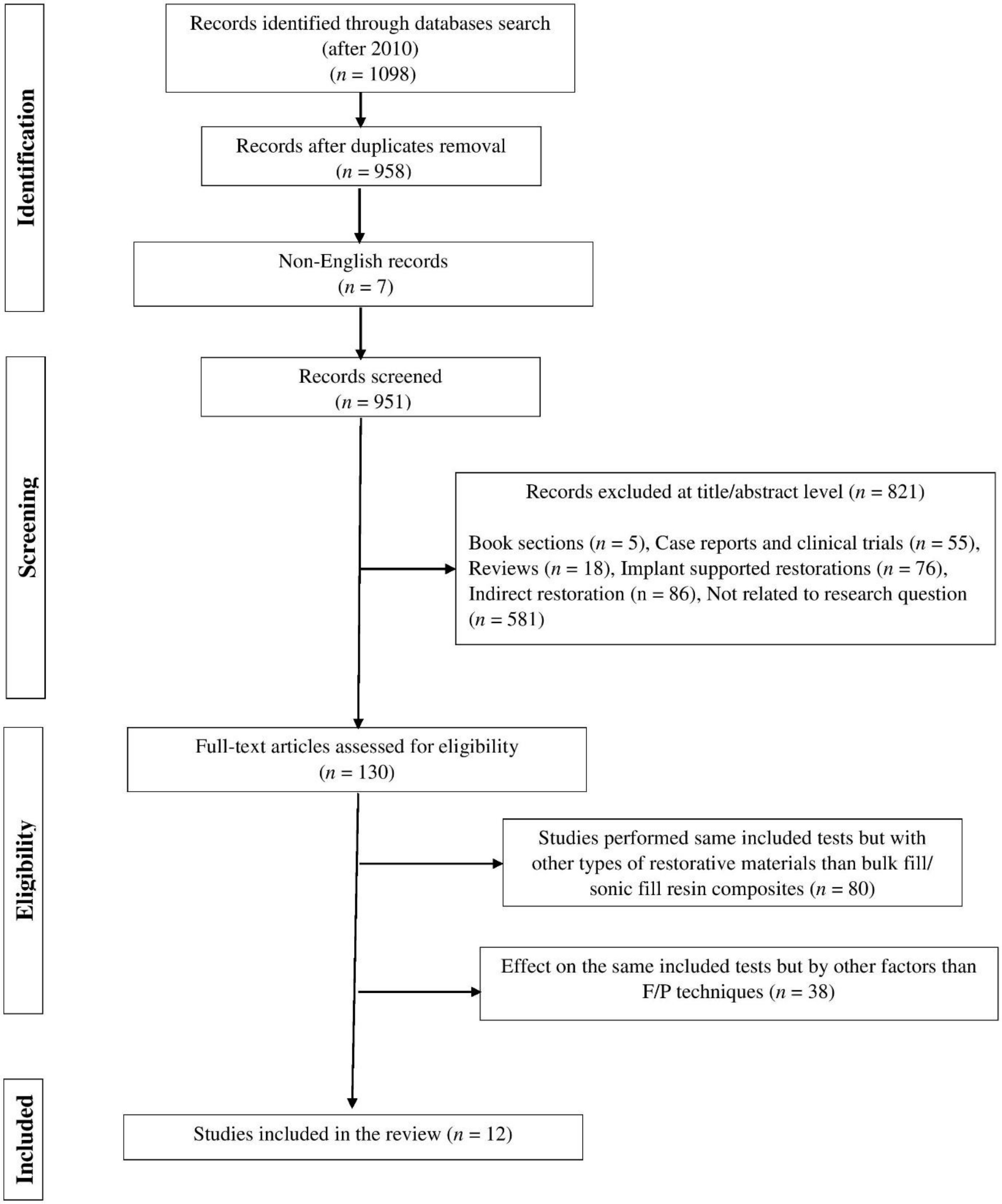


Fig. 1. Search flowchart as adapted from the PRISMA Statement

Table 1. Assessment of sample sizes, scientific categories and brand names of restorative materials and F/P systems used

Study	Sample type and size and cavity type	Restorative materials used	Specimen grouping according to F/P systems used
Oktay et al. [20]	36 cylindrical specimens (2mm H × 10mm D)	- Nanohybrid flowable bulk fill RC with sonic activation (SonicFill)	- Liquid polish (Biscover LV)
			- Multi-step system (Soflex discs) (medium to super fine)
Lassila et al. [21]	147 block shaped specimens (40mm Lx 10mm W × 2mm T)	- Nanofilled regular bulk fill RC (Filtek Bulk Fill) - Bioactive composite (ACTIVA-Restorative) - Short-fiber reinforced composite (Alert) -Short-fiber reinforced flowable composite (everX Flow)	- SiC grit size 320
			- SiC grit size 800
			- SiC grit size 1200
			- SiC grit size 2000
			- SiC grit size 4000
			- Two-step system (Sof-Lex spiral) (Beige and pink)
			- One-step system (Jiffy abrasive polishing points /yellow)
Ishii et al. [22]	70 cylindrical specimens (2mm H × 10mm D)	- Nanohybrid regular bulk fill RC (Tetric EvoCeram Bulk Fill) - Nanofilled regular bulk fill RC (Filtek Bulk Fill) - Microhybrid flowable bulk fill RC (Filtek Bulk Fill Flowable)	- SiC grit size 320
			- SiC grit size 320 + Super fine grit diamond bur
			- SiC grit size 320 + Tungsten carbide bur
			- SiC grit size 320 + Super fine grit diamond Bur + One-step system (Compomaster)
			- SiC grit size 320 + Tungsten carbide bur + One-step system (Compomaster)
			- SiC grit size 320 + Super fine grit diamond Bur + Multi-step system (Super-Snap) (fine and superfine)
			- SiC grit size 320 + Tungsten carbide bur + Multi-step system (Super-Snap)
Gurbuz et al. [23]	60 cylindrical specimens (2mm H × 10mm D)	- Giomer based bulk fill RC (Beautifil-Bulk Restorative) - Nanofilled regular bulk fill RC (Filtek Bulk Fill)	- Multi-step system (OptiDisc) (extra-coarse to extra-fine)
			- Multi-step system (OptiDisc) + Liquid polish (Biscover LV)
Granat et al. [24]	48 cylindrical specimens (2mm or 4mm H × 10mm D)	- Nanohybrid regular bulk fill RC (Tetric EvoCeram Bulk Fill, X-tra fil) - Nanofilled regular bulk fill RC (Filtek Bulk Fill) - Microhybrid regular bulk fill RC(QuiXfil)	- Two-step polishing system (Politip)

de Fátima Alves da Costa et al. [25]	180 cylindrical specimens (2mm H × 8mm D)	- Nanofilled regular bulk fill RC (Filtek Bulk Fill) - Nanohybrid regular bulk fill RC (Tetric N-Ceram Bulk Fill, X-tra Fil) - Microhybrid regular bulk fill (Opus Bulk Fill)	- Multi-step system (Astropol) (Finish, polish, high gloss polish)
			- Multi-step system (Astropol) (Finish, polish, high gloss polish) + One-step system (Astrobrush)
Bilgili et al.[26]	132 cylindrical specimens (1mm H × 10mm D)	- Nanohybrid flowable bulk fill RC with sonic activation (SonicFill 2) - Nanofilled regular bulk fill RC (Filtek Bulk Fill) - Nanohybrid ormocer bulk fill (Admira Fusion X-tra) - Giomer based bulk fill RC (Beautifil-Bulk Restorative)	- Multi-step system (Soflex discs) (coarse to super fine)
Rigo et al. [27]	126 cylindrical specimens (2mm H × 5mm D)	- Microhybrid flowable bulk fill RC (SureFil SDR, Filtek Bulk Fill Flowable) - Nanohybrid flowable bulk fill RC (Tetric EvoFlow Bulk Fill) - Nanofilled regular bulk fill RC (Filtek Bulk Fill) - Nanohybrid regular bulk fill RC (Tetric EvoCeram Bulk Fill)	- Multi-step system (Soflex discs) (Coarse to superfine) - Two-step system (Sof-Lex spiral) (Beige and white)
			- Multi-step system (Astropol) (Finish, polish, high gloss polish)
Ehrmann et al. [28]	60 cylindrical specimens (1mm H × 5mm D)	- Nanohybrid regular bulk fill RC (Tetric EvoCeram Bulk Fill)	- Blue-and-yellow-ring Q crosscut 12/15-fluted finishing bur - One-step system (EVO-Light polisher)
			- Blue-and-yellow-ring Q crosscut 12/15-fluted finishing bur- White-ring crosscut 30-fluted polishing bur- One-step system (EVO-Light polisher)
Magdy et al. [29]	60 cylindrical specimens (2mm H × 8mm D)	- Nanohybrid regular bulk fill RC (Tetric N-Ceram Bulk Fill)	- SiC grit size 320- Multi-step system (Eve discs) (Coarse to superfine)
Cazzaniga et al. [30]	108 cylindrical specimens (1.5mm H × 6mm D)	- Nanohybrid flowable bulk fill RC with sonic activation (SonicFill 2)	- Multi-step system (Soflex discs) (medium to superfine)
			- One-step rubber points system (Opti1Step)
			- Diamond burs (red followed by yellow coded)
			- Multi-blade carbide bur (12 bladed followed by 30 bladed)
Kumari et al. [31]	30 cylindrical specimens (2mm H × 8mm D)	- Microhybrid flowable bulk fill RC (SureFil SDR) - Short-fiber reinforced bulk fill RC (C-Ever X)	- Multi-step system (Super-Snap Rainbow) (Coarse to extra fine)

H: Height; D; Diameter; RC: Resin composite; L: Length; W: Width; T: Thickness; SiC: Silicon carbide

Table 2. Bulk fill restorative materials evaluated in the included studies

Commercial name/ Manufacturer	Classification	Matrix composition	Filler types	Filler load (wt.%)	Average particle size
Regular bulk fill composite					
Filtek Bulk Fill (3M ESPE, St Paul, MN, USA)	Nanofilled	AUDMA, UDMA, DDDMA	Silica, Zirconia, ytterbium trifluoride	76.5	0.004-0.1µm
Tetric EvoCeram Bulk Fill (Ivoclar Vivadent, NY, USA)	Nanohybrid	Bis-GMA, UDMA, bis-EMA	Barium glass, ytterbium trifluoride, mixed oxide prepolymer	82-84	550nm
Opus Bulk Fill (FGM, Joinville, SC, Brasil)	Microhybrid	UDMA	Silanized silica dioxide	79	0.7–1µm
X-tra fil (VOCO GmbH, Cuxhaven, Germany)	Nanohybrid	Bis-GMA, UDMA, TEGDMA	Barium-boron-aluminosilicate glass	86	0.05-10µm
QuiXfil (Dentsply, Konstanz, Germany)	Microhybrid	UDMA, TEGDMA, di- & trimethacry-late resins, carboxylic acid-modified methacrylate resins	Silanized strontium-aluminum glass with the addition of sodium fluoride	86	1 - 10µm
Admira Fusion x-tra (VOCO GmbH, Cuxhaven, Germany)	Nanohybrid	Ormocer	Barium-aluminum-silicate glass / Silica nanoparticles	84	60% of the particulate is between 20-40nm
Tetric N-Ceram Bulk Fill (Ivoclar Vivadent, Schaan, Liechtenstein)	Nanohybrid	Bis-GMA, bis-EMA, UDMA	Barium glass, ytterbium trifluoride	75-77	0.4-0.7µm
Beautifil-Bulk Restorative (Shofu Dental Corp. Kyoto, Japan)	Giomer	Bis-GMA, UDMA, Bis MPEPP, TEGDMA	Pre-reacted glass-ionomer based fillers/Barium-aluminum-silicate glass	87	Unreported
Flowable bulk fill resin composite with sonic activation					
SonicFill (Kerr Corporation, Orange, CA, USA)	Nanohybrid	Bis-GMA, Bis-EMA, TEGDMA	Silicon dioxide, barium glass	83.5	Unreported
SonicFill 2ation, Orange, CA, USA)	Nanohybrid	TMSPMA, Bis-EMA, bisphenol-A-bis-(2 hydroxy-3-methacryloxypropyl) ether, TEGDMA	Silicon dioxide, barium glass	81.3	Unreported
Flowable bulk fill resin composite					
Filtek Bulk Fill Flowable (3M ESPE, St Paul, MN, USA)	Microhybrid	Bis-GMA, UDMA, substituted dimethacrylate, (BisEMA-6), & Procrylat resins	Zirconia/silica particles & ytterbium trifluoride fillers	64.5	0.01–5µm
SureFil SDR (Dentsply Caulk, Milford, USA)	Microhybrid	UDMA, EBPDMA, TEGDMA	Barium alumino-fluoro borosilicate glass	68	4.2µm
Tetric EvoFlow Bulk Fill (Ivoclar Vivadent, NY, USA)	Nanohybrid	Bis-GMA, Bis-EMA, TCDD	Barium glass, ytterbium trifluoride, copolymers	68.2	0.1-30µm

AUDMA: aromatic urethane dimethacrylate; UDMA: urethane dimethacrylate; DDDMA: 12-dodecanediol dimethacrylate; Bis-GMA: bisphenol-A-glycidyl-dimethacrylate; Bis-EMA: ethoxylated bisphenol-A-dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; Bis MPEPP: 2,2-bis(4-methacryloxypolyethoxyphenyl) propane; TMSPMA: 3-trimethoxysilylpropyl methacrylate; EBPDMA: ethoxylated bisphenol A dimethacrylate; TCDD: Tetrachlorodibenzo-p-dioxin

Table 3. Finishing and polishing systems evaluated in the current study

System/Manufacturer	Type of procedure	Types of abrasive particles	Average abrasive particle size
Trimming and abrading F/P burs			
Diamond (red coded) (Komet, Lemgo, Germany)	F	Diamond	30-40µm
Super fine grit diamond (Shofu, Kyoto, Japan) and (Komet, Lemgo, Germany)	F	Diamond	20-25µm
Tungsten carbide (Kerr, Orange, CA, USA)	F	Tungsten carbide flutes	12 bladed
Blue-and-yellow-ring crosscut 12/15-fluted finishing (Komet, Lemgo, Germany)	F	Tungsten carbide flutes	15 bladed
White-ring crosscut 30-fluted polishing (Komet, Lemgo, Germany)	P	Tungsten carbide flutes	30 bladed
Coated and bonded abrasives			
Sic papers			
SiC grit size 320, 800, 1200, 2000, 4000	F	Silicon carbide	40, 22, 15, 5µm
Multi-step systems			
Soflex discs (3M, Dental products St Paul, MN, USA)	F&P	Aluminum oxide	Coarse disc: 100µm medium disc: 40µm Fine disc: 24µm Ultra-fine disc: 8µm
Super-Snap (Shofu Dental Corp., California, USA)	F&P	Aluminum oxide	Black (coarse): 60µm Violet (medium): 30µm Green (fine): 20 µm Red (superfine): 7 µm
OptiDisc (Kerr Hawe, Karlsruhe, Germany)	F&P	Aluminum oxide	Extra-coarse: 80µm Coarse: 40 µm Fine: 20µm Extra-fine: 10µm
Eve discs (EVE Ernst Vetter GmbH, Keltern, Germany)	F&P	Aluminum oxide	Blue (Coarse): 75µm Red (Medium): 40µm Yellow (Fine): 20µm White (X-Fine): 8µm
Astropol (Ivoclar Vivadent, NY, USA)	F&P	Silicon carbide	Grey: 45µm Green: 1µm Dusky pink: 0.3µm
Two-step systems			
Soflex spiral (3M, Dental products St Paul, MN, USA)	F&P	Aluminum Oxide or diamond (pink spiral)	Beige (finishing) White (polishing) Pink (polishing)
Politip (IvoclarVivadent, Schaan, Liechtenstein)	F&P	Silicon carbide	NS
One-step system			
Jiffy abrasive polishing points /yellow (Ultradent, South Jordan, UT, USA)	P	Silicon carbide	30µm
Compomaster (Shofu Dental Corp, California, USA)	P	Diamond	6µm
EVO-Light polisher ((Komet, Lemgo, Germany)	P	Diamond	8µm
Opti1Step (Kerr Corp., Orange, California, USA)	P	NS	NS
Abrasive impregnated brushes			
Astrobrush (Ivoclar Vivadent, New York)	P	Silicon carbide	NS
Liquid polisher			
Biscover LV (Bisco Inc, Schaumburg, IL, USA)	P	Low viscosity liquid polish	

F: Finishing; P: Polishing; SiC: Silicon carbide; NS: not specified

Risk of bias assessment

According to the parameters considered in the analysis, four studies presented a medium-risk of bias [22,24,27,29], whereas eight investigations showed a high-risk of bias [20,21,23,25,26,28,30,31]. The risk of bias graph and summary are illustrated in Figure 2.

Assessment of surface roughness:

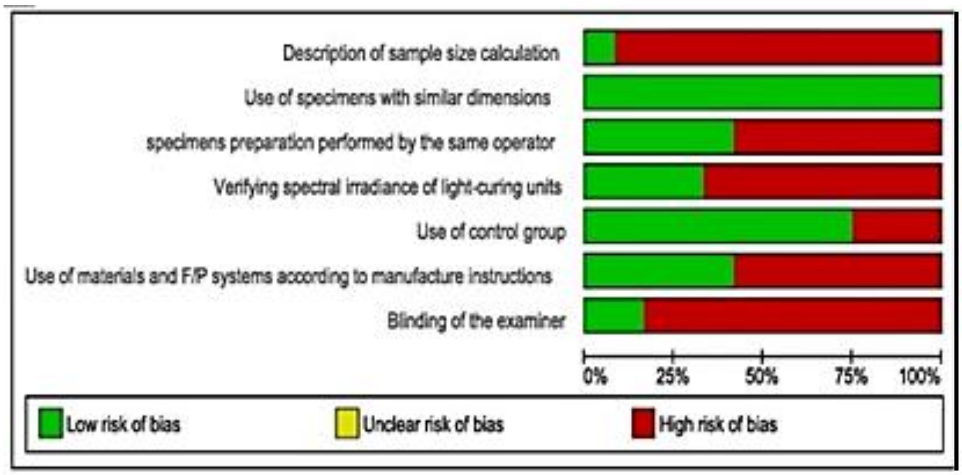
Testing methodology:

Table 4 presents the methods for evaluating roughness in current review.

Assessment of surface roughness results

Quantitative assessment for BF

Two studies found no significant difference in roughness values when compared control groups of nanofilled and nanohybrid regular BF [22,27]. On the contrary, one study reported significant smoother surface for nanofilled than nanohybrid control groups [25]. Two studies found significantly lower roughness values for nanofilled than nanohybrid BF when both finished and polished using multi-step systems



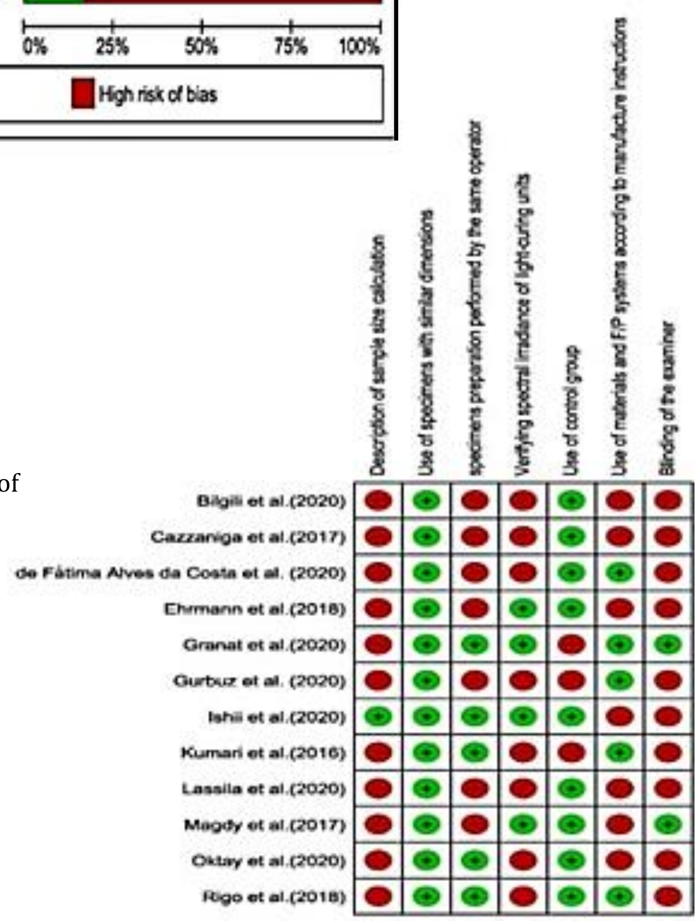


Fig. 2. Risk of bias graph (upper) and risk of bias summary

Table 4. Assessment of roughness test methodology

Study	Quantitative assessment	Reads per specimen (N)	Unit	Qualitative assessment
Oktay et al. [20]	Profilometer (Ra)	3	µm	-
Lassila et al. [21]	-	-	-	Noncontact optical profilometer (3D)
Ishii et al. [22]	3D laser scanning microscope (Ra)	5	µm	SEM (×2500)
Gurbuz et al. [23]	Profilometer (Ra)	3	µm	-
Granat et al. [24]	Profilometer (Ra)	5	µm	SEM (×1000/×3000)
de Fátima Alves da Costa et al. [25]	Rugosimeter with piezoelectric transducer	3	µm	AFM SEM (×500)
Bilgili et al. [26]	Profilometer (Ra)	3	µm	SEM (×1000/×5000/×10000)
Rigo et al. [27]	Optical topometry (Ra)	5	µm	Optical topometry (3D) (2D at ×50)
Ehrmann et al. [28]	Optical Profilometer (Ra)	NS	µm	Optical microscope (×50) SEM (×100, ×500, ×2000)
Magdy et al. [29]	Profilometer (Ra)	NS	µm	SEM (×2000)
Cazzaniga et al. [30]	Profilometer (Ra)	NS	µm	SEM (×5000)
Kumari et al. [31]	AFM (Ra) (Rp-v)	6	nm	AFM

Ra: Roughness average; SEM: Scanning electron microscope; AFM: Atomic force microscope; Rp-v: Maximum peak-to-valley distance, NS: not specified

[22,25], while another study reported the opposite [27].

Two of the included studies indicated that flowable BF had comparable Ra values with regular BF [22,27]. Roughness values were significantly higher in microhybrid BF compared to other BF categories in two other studies [24,31]. Short fiber reinforced BF was found to have comparable roughness values to other BF composites in two included studies [21,31].

Qualitative assessment for BF

One study performed a descriptive evaluation by scanning electron microscope (SEM) for the surfaces of nanofilled, nanohybrid and microhybrid BF. They found that the nanohybrid (Tetric EvoCeram BF) had a smooth surface with slight damage compared to the rough surfaces of the nanofilled (Filtek Bulk Fill) and microhybrid BF composites used, and this was inconsistent with the quantitative analysis [24].

Quantitative assessment for F/P systems

Regardless of the BF composite used, seven studies found that different F/P systems; multi-step, one-step, carbide and diamond finishing burs and liquid polisher, showed higher roughness values than control specimens (Mylar) [22,25-30].

One study concluded that super fine grit diamond burs created a roughness of more than 12 fluted carbide burs when used with both nanofilled and nanohybrid regular BF [22]. Another study reported that using cross-cut 30 fluted following 15 fluted carbide burs generated a significantly smoother surface when used with a nanohybrid regular BF [28]. Multi-step systems created smoother surfaces than one-step, fine grit diamond and carbide finishing burs in two studies when used with a sonic-activated flowable BF resin composite, nanofilled and regular nanohybrid BF [22,30]. One study combined the use of either super fine grit diamond or 12 fluted carbide burs with either multi-step or one-step systems, and they found that the smoothest surfaces were accomplished using 12 fluted carbide burs followed by a multi-step system [22].

Additional polishing using an abrasive impregnated brush after a multi-step system significantly reduced the roughness of different regular BF composites as found in one included study [25]. Two studies reported that the use of liquid polisher after F/P resulted in similar Ra values for multi-step discs [20,23].

Qualitative assessment of F/P systems

Overall, 2D and 3D qualitative analysis coincided with quantitative data for both BF composites and F/P systems in the included studies [21,22,24,25,29,30].

Assessment of microbial adhesion:

Testing methodology:

The testing methodology used in the current review is shown in Table 5.

Table 5. Assessment of microbial adhesion test methodologies

Study	Microorganism	Quantitative evaluation	Qualitative evaluation	Incubation period (h)	Unit	Artificial saliva
Oktay et al. [20]	*Candida Albicans*	Colorimetric technique (by ELISA reader)	-	48	OD	No
Bilgili et al. [26]	*S. mutans* and *S. mitis*	Colony count	CLSM	24	×108 CFU/ml	Yes
Cazzaniga et al. [30]	*S. mutans*	Colorimetric technique (by spectrophotometer)	CLSM	24	OD	Yes

OD: Optical density; CLSM: Confocal laser scanning microscope; CFU: Colony forming units;

Assessment of microbial adhesion results

Quantitative assessment of BF

Bilgili et al. [26] found no significant difference in *S. mutans* adhesion on different BF composites. They evaluated a regular flowable, nanofilled BF resin composite with sonic activation, and an ormocer-based and giomer-based BF. All specimens were finished and polished with the same multi-step system. In contrast, they also found a significant adhesion of *S. mitis* on flowable BF resin composite with sonic activation compared to the other types.

Qualitative assessment of BF

One of the studies included in the current review, detected a high prevalence of dead *S. mutans* by confocal laser scanning microscopy on giomer-based and nanofilled regular BF composites, which was more than that found in flowable BF resin composite with sonic activation, as well as ormocer-based composites [26].

Quantitative assessment for F/P systems

C. albicans biofilm formation was more advanced on a flowable BF resin composite with sonic activation when polished with a liquid polisher than that observed in the multi-step system [20]. Conversely, another study found a non-significant difference in *S. mutans* biofilm formation on the same BF materials when finished and polished with different systems [30].

Meta-analysis results

Due to the heterogeneous experimental conditions, only three studies fulfilled the eligibility criteria to be included in the meta-analysis. The results of this meta-analysis showed that there was no significant difference in the pooled Ra means for both nanofilled (Filtek Bulk Fill) and nanohybrid (Tetric EvoCeram Bulk Fill) regular BF composites, either when no F/P were performed [Table 6 and Figure 3 (left)] or when finished and polished with the same multi-step systems [Table 7and Figure 3 (right)].

Table 6. Results of the meta-analysis for Filtek Bulk Fill and Tetric EvoCeram Bulk Fill composites without F/P

	N1	N2	Total	SMD	SE	95% CI	t	P
Ishii et al. [22]	10	10	20	0.95	0.45	0.003 to 1.91	-	-
de Fátima Alves da Costa et al. [25]	10	10	20	-2.36	0.56	-3.55 to -1.17	-	-
Rigo et al. [27]	6	6	12	-0.30	0.53	-1.5 to 0.88	-	-
Total (fixed effects)	26	26	52	-0.32	0.29	-0.92 to 0.26	-1.1	0.27
Total (random effects)	26	26	52	-0.54	0.96	-2.48 to 1.39	-0.56	0.57

N1: number of specimens for nanofilled regular bulk fill; N2: number of specimens for nanohybrid regular bulk fill; SMD, standardized mean difference; SE: standard error; CI: confidence interval

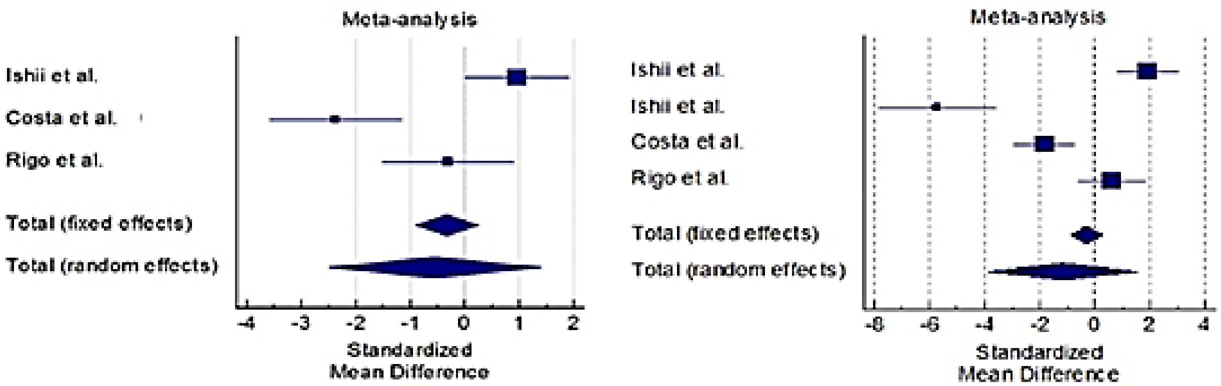


Fig. 3. Forest plots of the meta-analysis for Filtek Bulk Fill and Tetric EvoCeram Bulk Fill composites without F/P. D (left) and Filtek Bulk Fill and Tetric EvoCeram Bulk Fill composites finished and polished with multi-step systems (right)

Table 7. Results of the meta-analysis for Filtek Bulk Fill and Tetric EvoCeram Bulk Fill composites finished and polished with multi-step systems

Study	N1	N2	Total	SMD	SE	95% CI	t	P
Ishii et al. [22]	10	10	20	1.91	0.52	0.81 to 3.01	-	-
Ishii et al. [22]	10	10	20	-5.74	1	-7.85 to -3.63	-	-
de Fátima Alves da Costa et al. [25]	10	10	20	-1.84	0.51	-2.93 to -0.75	-	-
Rigo et al. [27]	6	6	12	0.61	0.54	-0.6 to 1.83	-	-
Total (fixed effects)	36	36	72	-0.3	0.29	-0.88 to 0.27	-1.04	0.3
Total (random effects)	36	36	72	-1.15	1.33	-3.82 to 1.5	-0.86	0.38

N1: number of specimens for nanofilled regular bulk fill; N2: number of specimens for nanohybrid regular bulk fill; SMD: standardized mean difference; SE: standard error; CI, confidence interval.

DISCUSSION

Rationale

Control groups of bulk filling composites, cured against the Mylar strip without any further F/P, were assessed in this review as they clinically simulate the proximal surfaces with neighboring teeth receiving no F/P. Curing the materials against Mylar strips is often clinically insufficient because post-curing F/P procedures must be performed to remove excess material and obtain the correct anatomical form [5]. In addition, there is a large variety of F/P systems and techniques available [13], which is why this review aimed to summarize them and find out which systems yield the best results regarding BF composite smoothness and microbial adhesion. We included only in vitro studies as the performance of F/P systems on BF composites has been investigated in these types of studies and has not been confirmed by clinical studies to date. The ten-year period for this review was based on a preliminary search for studies evaluating roughness and microbial adhesion of BF composites, and it was found that they were all within the last 5 to 6 years.

Meta-analysis

The most frequently used BF composites in the included studies were Filtek Bulk Fill and Tetric EvoCeram Bulk Fill. Therefore, we conducted a meta-analysis to compare both materials. The meta-analysis revealed non-statistically significant differences in Ra values of the control groups for both materials. This can be explained by the fact that after compression applied through the Mylar strip on the surface of the composite, it is possible that particles can slide into the organic matrix, so that the smaller particles, with lower density, are closer to the top compared to larger particles. [33]. This interpretation justifies the fact that purely nanofilled composites have an SR similar to other nanohybrid types since larger particles did

not participate in the surface composition.
Previous studies suggest that SR mainly depends on resin composite formulation like filler size, loading and type of resin matrix [34,35]. The resin matrix is relatively soft as compared to the relatively hard inorganic fillers; therefore, they do not abrade to the same degree when F/P instruments are used [28]. This usually results in more wear of the organic matrix than the fillers that may be left protruding from the surface after F/P [32]. This explains why larger filler particles correspond to more rough composite surfaces after F/P procedures [34]. This may also explain the significant difference in surface smoothness between BF microhybrid composites and BF nanohybrid or BF nanofilled composites as reported in three of the included studies, regardless of the viscosity [24,25,31].
In contrast to the previous data, the results of the meta-analysis of this review revealed no significant differences in Ra values between Filtek Bulk Fill (Nanofilled) and Tetric EvoCeram Bulk Fill (Nanohybrid) when polished with the same multi-step system. This may be explained by the modifications in the composition of both materials; Tetric EvoCeram Bulk Fill features a more efficient photointiator (Ivocerin, Ivoclar Vivadent) than camphorquinone, increase in the translucency of the material, and the addition of smaller-size rounded fillers resulting in a deeper, more efficient degree of polymerization and better polishing performance [36]. In addition, purely spherical fillers, which have been reported to allow a higher filler packing ratio, would lead to higher wear resistance associated with the smooth surface after polishing [37].
Regarding Filtek Bulk Fill, modifications are made to the matrix. Two low-viscosity monomers: urethane dimethacrylate (UDMA) and 12-dodecanediol dimethacrylate (DDDMA) were incorporated to reduce reactive groups in the material to moderate the shrinkage [27], this mechanism relaxes the material and relieves stress. Previous studies suggested that UDMA elution on Filtek Bulk Fill was considerably higher and its degree of cure was lower compared to other BF composites [38]. These properties may contribute to increased abrasion of the matrices during polishing and exposure of superficial fillers, resulting in increased roughness [39]. This may also explain the insignificant Ra values in the included studies that compared the same material to different types of nanohybrid regular BF [26].

Quantitative assessment of roughness values of BF composites

It was reported that conventional flowable composites have smoother surfaces than regular conventional composites due to their lower filler rate [40]. Conversely, two of the included studies reported that flowable BF had comparable Ra values in contrast to regular BF [22,27]. This may be attributed to the increased filler size of the flowable BF by the manufacturer used in both studies that led to the modification of the surface characteristics of these materials [27].
The relatively smooth surface of short fiber reinforced BF after F/P compared to other BF composites in two of the included studies was explained by Lassila et al [21], who noticed that there was no protrusion of microfibers of this type of composite and they were polished down together with a resin matrix.

Qualitative assessment of the roughness values of BF composites

Comparative qualitative assessment of nanofilled (Filtek Bulk Fill) and nanohybrid (Tetric EvoCeram Bulk Fill) in one of the included studies revealed that nanohybrid used had a relatively good qualitative description of the surface after polishing compared to the nanofilled BF, in contrast to the quantitative assessment [24]. The rough surface of this nanofilled BF assessed by SEM might be related to the loss of larger filler particles that deteriorated their qualitative assessment.

Finishing and polishing procedures

Finishing and polishing procedures were performed in most of the included studies immediately after light curing. Previous reports demonstrated that immediate polishing did not produce negative impact on the SR, microhardness, and microleakage of resin-based composites compared to late polishing [24,41]. In addition, this would reduce the number of clinical sessions [24]. Both wet and dry F/P procedures were used in the included studies. Nasoohi et al. [42] reported that dry F/P of resin composites can increase SR values because the

abrasive particles separated from the polishing tool may be embedded into the composite surface. In contrast, Kaminedi et al. [43] concluded that dry F/P gave the best smoothness and hardness values in nanohybrid composite. Regardless of the conflict of which technique results in smoother surfaces, consideration must be given to the excessive heat generation that can result from dry F/P and which may degrade the filler/matrix bond.

Quantitative and qualitative assessment for F/P systems

While using different composites, finishing diamond grits and fluted carbide burs were compared and the results showed that the latter exhibited smoother surfaces [22]. This could be related to the structure and cutting technique of each. Fluted carbide burs have several fine blades that cut away the filler particles so that a proportion of these fillers are embedded in the surface, resulting in a smoother surface, whereas diamond burs grind the surface with many abrasive diamond particles that may have promoted plucking of filler particles, generating voids in the resin surface and making it rougher [22].

Multi-step aluminum oxide discs were found to create significantly smoother surfaces compared to one-step systems in two of the included studies [22, 30]. The better results for the multi-step discs may have been due to their polishing mechanism. The multi-step discs include different discs with progressively finer grit size that abrade filler particles and resin matrix equally [22, 30]. In addition, it has also been reported that SR strongly depend on polishing time and application force [44]. This may be in favor of multi-step discs and may explain the difference in results.

A study concluded that additional polishing using a silicon carbide impregnated brush after multi-step system created more uniform wear for the surface and significantly reduced the roughness of different regular BF composites [25]. However, it must be emphasized that this impregnated brush should be used as an additional step after polishing and not as a separate step [45,46].

Surface sealants have been reported to provide a smooth, wear-resistant surface that has increased in the longevity of resin composites [47]. The observed smooth surfaces of BF composites after surface sealants application, in two of the included studies [20,23], are attributed to the low viscosity of these sealants enabling them to penetrate and fill the structural micro defects, thus providing a more uniform and smoother surface [47]. However, these materials are subjected to degradation over time and must be applied annually [48].

Microbial adhesion

Different surface parameters have been reported to affect microbial adhesion to the surface of restorative materials, including SR, SFE and hydrophobicity [8]. One of the included studies observed more *C. albicans* adhesion on smoother surfaces [20], in contrast to the hypothesis that *C. albicans* presents more on rough surfaces as reported previously [49]. In fact, other studies have not found a conclusive relation between roughness and *C. albicans* adhesion [50, 51]. On the basis of these conflicting findings, Oktay et al, [20] concluded that presence of residual monomer due to inadequate polymerization and surface contact angle may be more critical for *C. albicans* adhesion than SR. It is noteworthy mentioning that this included study did not use saliva to condition samples [20], although it was found that presence of salivary proteins may affect the *C. albicans* adhesion [52].

In the literature, F/P procedures are considered to be able to influence biofilm formation by affecting SR and other parameters related to surface characteristics. An increase in SR enhances biofilm formation by reducing the shear force on growing microbes [53]. Conversely, one of the included studies could not find a clear association between different Ra values and *S. mutans* adhesion to different BF composites with different F/P systems [30]. This conflicting data could be due to three reasons explained by previous authors: Roughness-induced irregularities can protect bacteria against shear forces during the early stages of biofilm formation, while this parameter seems less important in influencing full-grown biofilm [51]. Some studies that directly correlate roughness with microbial adhesion, compare roughness values much higher versus much lower than the threshold value (0.2μm). Another

possible explanation could be related to conditioning the specimen with saliva before the adhesion test. It was reported that saliva pellicle has a significant effect on bacterial adhesion to teeth and restoration surfaces [26]. This is because the pellicle layer affects not only the biofilm resistance, but also its composition and enzymatic activities [54]. Based on previous data, it would not be accurate to compare studies with different experimental designs.

It was reported that there is a positive correlation between microbial adhesion and SFE [20], and this may explain why flowable BF resin composite with sonic activation, with the highest SFE, had the highest *S. mitis* adhesion among the other BF composites [26]. Previous authors concluded that hydrophobic bacterial strains, like *S. mutans*, demonstrated the highest adherence onto hydrophobic materials, while hydrophilic strains, like *S. mitis*, adhered more onto hydrophilic surfaces [55]. This finding may also explain the increased adhesion of *S. mitis* on flowable BF resin composite with sonic activation with its relatively hydrophilic surfaces compared to other tested BFs [26]. *C. albicans* was reported to be rather hydrophilic with water contact angles between 23 and 51°. Consequently, relative hydrophilic material surfaces with lower contact angles should be more prone to its adhesion compared to hydrophobic materials [50]. On the contrary, one of the included studies reported lower *C. albicans* adhesion on flowable BF resin composite with sonic activation with its relatively hydrophilic surface. In addition, the same authors observed more *C. albicans* adhesion to surfaces treated with liquid polish, which is considered the most hydrophobic surface polishing used in this study [20]. This is consistent with the findings of previous studies that did not detect a relationship between hydrophobicity of resin-based composites and microbiological adhesion [56,57]. These conflicting data can be explained by the fact that the interaction between the surface and adhered microorganism is not solely dependent on hydrophobicity.

The chemical composition of resin-based materials has been indirectly linked to biofilm formation [26,30]. Bilgili et al, [26] stated that one of the reasons for the increased adhesion of *S. mitis* on the flowable BF resin composite with sonic activation is the presence of TEGDMA in its resin content. Moreover, they linked their observations regarding the presence of more dead bacteria on the surface of some of the BF composites with their fluoride content [26]. In contrast, Cazzaniga et al, [30] reported that the amount of fluoride in one of their tested resin composites did not show any significant reduction in biofilm formation. This may emphasize that antibacterial activity does not always coincide with the ability of a given material to prevent bacterial adhesion on its surfaces [58]. Moreover, the percentage of fluoride content and release pattern should be considered when correlating fluoride and biofilm adhesion [30].

Limitations and recommendations:

This review presents some limitations, including the exclusion of non-English manuscripts and the included studies were only laboratory. Moreover, the studies included in the meta-analysis were just 3 out of 12 studies due to the heterogeneity in types of BF composites and F/P systems evaluated. Furthermore, clinical studies relating to the same questions raised in this review are needed, along with all included studies evaluated smoothness and microbial adhesion immediately after F/P, so the longevity of F/P systems effects should also be evaluated.

CONCLUSION

Based on the findings of this systematic review, the following conclusions may be drawn: despite the differences in filler particle sizes of Filtek Bulk Fill and Tetric EvoCeram Bulk Fill, they have comparable surface smoothness, with or without F/P. The difference in viscosity of BF composites has no effect on SR. Considering the accessibility and anatomy of the surfaces to be polished, the best potential F/P systems that could be used with BF composites are multi-step discs. Finishing with fluted carbide burs may be preferable as compared to diamond finishing stones. Microbial adhesion is mainly affected by surface chemistry and other surface parameters rather than only SR.

CONFLICT OF INTEREST STATEMENT

None declared.

REFERENCES

1. Garoushi S, Vallittu PK, Lassila L. Characterization of fluoride releasing restorative dental materials. Dent Mater J. 2018 Mar 30;37(2):293-300.
2. Benetti AR, Havndrup-Pedersen C, Honoré D, Pedersen MK, Pallesen U. Bulk-fill resin composites: polymerization contraction, depth of cure, and gap formation. Oper Dent. 2015 Mar-Apr;40(2):190-200.
3. Shimokawa C, Giannini M, André CB, Sahadi BO, Faraoni JJ, Palma-Dibb RG, et al. In Vitro Evaluation of Surface Properties and Wear Resistance of Conventional and Bulk-fill Resin-based Composites After Brushing With a Dentifrice. Oper Dent. 2019 Nov/Dec;44(6):637-647.
4. Haugen HJ, Marovic D, Par M, Thieu MKL, Reseland JE, Johnsen GF. Bulk Fill Composites Have Similar Performance to Conventional Dental Composites. Int J Mol Sci. 2020 Jul 20;21(14):5136.
5. Teughels W, Van Assche N, Sliepen I, Quirynen M. Effect of material characteristics and/or surface topography on biofilm development. Clin Oral Implants Res. 2006 Oct;17 Suppl 2:68-81.
6. Ferracane JL. Resin composite--state of the art. Dent Mater. 2011 Jan;27(1):29-38.
7. Erdemir U, Yildiz E, Eren MM, Ozsoy A, Topcu FT. Effects of polishing systems on the surface roughness of tooth-colored materials. J Dent Sci. 2013 Jun 1;8(2):160-9.
8. Yuan C, Wang X, Gao X, Chen F, Liang X, Li D. Effects of surface properties of polymer-based restorative materials on early adhesion of Streptococcus mutans in vitro. J Dent. 2016 Nov;54:33-40.
9. Cazzaniga G, Ottobelli M, Ionescu A, Garcia-Godoy F, Brambilla E. Surface properties of resin-based composite materials and biofilm formation: A review of the current literature. Am J Dent. 2015 Dec;28(6):311-20.
10. Canali GD, Ignácio SA, Rached RN, Souza EM. One-year clinical evaluation of bulk-fill flowable vs. regular nanofilled composite in non-carious cervical lesions. Clin Oral Investig. 2019 Feb;23(2):889-897.
11. Van Ende A, De Munck J, Lise DP, Van Meerbeek B. Bulk-Fill Composites: A Review of the Current Literature. J Adhes Dent. 2017;19(2):95-109.
12. Frese C, Wolff D, Staehle HJ. Proximal box elevation with resin composite and the dogma of biological width: clinical R2-technique and critical review. Oper Dent. 2014 Jan-Feb;39(1):22-31.
13. Sirin Karaarslan E, Bulbul M, Yildiz E, Secilmis A, Sari F, Usumez A. Effects of different polishing methods on color stability of resin composites after accelerated aging. Dent Mater J. 2013;32(1):58-67.
14. Kaizer MR, de Oliveira-Ogliari A, Cenci MS, Opdam NJ, Moraes RR. Do nanofill or submicron composites show improved smoothness and gloss? A systematic review of in vitro studies. Dent Mater. 2014 Apr;30(4):e41-78.
15. Dutra D, Pereira G, Kantorski KZ, Valandro LF, Zanatta FB. Does Finishing and Polishing of Restorative Materials Affect Bacterial Adhesion and Biofilm Formation? A Systematic Review. Oper Dent. 2018 Jan/Feb;43(1):E37-E52.
16. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, et al Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev. 2015 Jan 1;4(1):1.
17. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009 Jul 21;6(7):e1000097.
18. Rosa WL, Piva E, Silva AF. Bond strength of universal adhesives: A systematic review and meta-analysis. J Dent. 2015 Jul;43(7):765-76.
19. Sarkis-Onofre R, Skupien JA, Cenci MS, Moraes RR, Pereira-Cenci T. The role of resin cement on bond strength of glass-fiber posts luted into root canals: a systematic review and meta-analysis of in vitro studies. Oper Dent. 2014 Jan-Feb;39(1):E31-44.
20. Oktay EA, Ersahan S, Sabuncuoglu FA, Tort H, Karaoglanoglu S. Impact of various finishing and polishing techniques and composite materials on Candida albicans biofilm formation. Med Mycol. 2020 Jul 1;58(5):698-702.
21. Lassila L, Säilynoja E, Prinssi R, Vallittu PK, Garoushi S. The effect of polishing protocol on surface gloss of different restorative resin composites. Biomater Investig Dent. 2020 Jan 3;7(1):1-8.
22. Ishii R, Takamizawa T, Tsujimoto A, Suzuki S, Imai A, Barkmeier WW, et al. Effects of Finishing and Polishing Methods on the Surface Roughness and Surface Free Energy of Bulk-fill Resin Composites. Oper Dent. 2020 Mar/Apr;45(2):E91-E104.
23. Gurbuz O, Cilingir A, Dikmen B, Ozsoy A, Mert Eren M. Effect of surface sealant on the surface roughness of different composites and evaluation of their microhardness. Eur Oral Res. 2020 Jan 1;54(1):1-8.
24. Granat M, Cieloszyk J, Kowalska U, Buczkowska-Radlińska J, Łagocka R. Surface Geometry of Four Conventional Nanohybrid Resin-Based Composites and Four Regular Viscosity Bulk Fill Resin-Based Composites after Two-Step Polishing Procedure. Biomed Res Int. 2020 Aug 12;2020:6203053.
25. de Fátima Alves da Costa G, Melo AMDS, de

Assunção IV, Borges BCD. Impact of additional polishing method on physical, micromorphological, and microtopographical properties of conventional composites and bulk fill. Microsc Res Tech. 2020 Mar;83(3):211-222.
26. Bilgili D, Dündar A, Barutçugil Ç, Tayfun D, Özyurt ÖK. Surface properties and bacterial adhesion of bulk-fill composite resins. J Dent. 2020 Apr;95:103317.
27. Rigo LC, Bordin D, Fardin VP, Coelho PG, Bromage TG, Reis A, et al. Influence of Polishing System on the Surface Roughness of Flowable and Regular-Viscosity Bulk Fill Composites. Int J Periodontics Restorative Dent. 2018 July/August;38(4):e79–e86.
28. Ehrmann E, Medioni E, Brulat-Bouchard N. Finishing and polishing effects of multiblade burs on the surface texture of 5 resin composites: microhardness and roughness testing. Restor Dent Endod. 2018 Nov 26;44(1):e1.
29. Magdy NM, Kola MZ, Alqahtani HH, Alqahtani MD, Alghmlas AS. Evaluation of Surface Roughness of Different Direct Resin-based Composites. J Int Soc Prev Community Dent. 2017 May-Jun;7(3):104-109.
30. Cazzaniga G, Ottobelli M, Ionescu AC, Paolone G, Gherlone E, Ferracane JL, Brambilla E. In vitro biofilm formation on resin-based composites after different finishing and polishing procedures. J Dent. 2017 Dec;67:43-52.
31. Kumari CM, Bhat KM, Bansal R. Evaluation of surface roughness of different restorative composites after polishing using atomic force microscopy. J Conserv Dent. 2016 Jan-Feb;19(1):56-62.
32. Jefferies SR. Abrasive finishing and polishing in restorative dentistry: a state-of-the-art review. Dent Clin North Am. 2007 Apr;51(2):379-97, ix.
33. Costa GFAD, Fernandes ACBCJ, Carvalho LAO, de Andrade AC, de Assunção IV, Borges BCD. Effect of additional polishing methods on the physical surface properties of different nanocomposites: SEM and AFM study. Microsc Res Tech. 2018 Dec;81(12):1467-1473.
34. Ergücü Z, Türkün LS. Surface roughness of novel resin composites polished with one-step systems. Oper Dent. 2007 Mar-Apr;32(2):185-92.
35. St-Pierre L, Martel C, Crépeau H, Vargas MA. Influence of Polishing Systems on Surface Roughness of Composite Resins: Polishability of Composite Resins. Oper Dent. 2019 May/Jun;44(3):E122-E132.
36. Jang JH, Park SH, Hwang IN. Polymerization shrinkage and depth of cure of bulk-fill resin composites and highly filled flowable resin. Oper Dent. 2015 Mar-Apr;40(2):172-80.
37. Jang JH, Park SH, Hwang IN. Polymerization shrinkage and depth of cure of bulk-fill resin composites and highly filled flowable resin. Oper Dent. 2015 Mar-Apr;40(2):172-80.
38. Lempel E, Czibulya Z, Kovács B, Szalma J, Tóth Á, Kunsági-Máté S, et al. Degree of Conversion and BisGMA, TEGDMA, UDMA Elution from Flowable Bulk Fill Composites. Int J Mol Sci. 2016 May 20;17(5):732.
39. Avsar A, Yuzbasioglu E, Sarac D. The Effect of Finishing and Polishing Techniques on the Surface Roughness and the Color of Nanocomposite Resin Restorative Materials. Adv Clin Exp Med. 2015 Sep-Oct;24(5):881-90.
40. Joniot S, Salomon JP, Dejou J, Grégoire G. Use of two surface analyzers to evaluate the surface roughness of four esthetic restorative materials after polishing. Oper Dent 2006; 31:39–46.
41. Venturini D, Cenci MS, Demarco FF, Camacho GB, Powers JM. Effect of polishing techniques and time on surface roughness, hardness and microleakage of resin composite restorations. Oper Dent. 2006 Jan-Feb;31(1):11-7.
42. Nasoohi N, Hoorizad M, Tabatabaei SF. Effects of Wet and Dry Finishing and Polishing on Surface Roughness and Microhardness of Composite Resins. J Dent (Tehran). 2017 Mar;14(2):69-75.
43. Kaminedi RR, Penumatsa NV, Priya T, Baroudi K. The influence of finishing/polishing time and cooling system on surface roughness and microhardness of two different types of composite resin restorations. J Int Soc Prev Community Dent. 2014 Dec;4(Suppl 2):S99-S104.
44. Waheeb N, Silikas N, Watts D. Initial polishing time affects gloss retention in resin composites. Am J Dent. 2012 Oct;25(5):303-6.
45. Gedik R, Hürmüzlü F, Coşkun A, Bektaş OO, Ozdemir AK. Surface roughness of new microhybrid resin-based composites. J Am Dent Assoc. 2005 Aug;136(8):1106-12.
46. Chour RG, Moda A, Arora A, Arafath MY, Shetty VK, Rishal Y. Comparative evaluation of effect of different polishing systems on surface roughness of composite resin: An in vitro study. J Int Soc Prev Community Dent. 2016 Aug;6(Suppl 2):S166-70.
47. Sarac D, Sarac YS, Kulunk S, Ural C, Kulunk T. The effect of polishing techniques on the surface roughness and color change of composite resins. J Prosthet Dent. 2006 Jul;96(1):33-40.
48. Takeuchi CY, Orbegoso Flores VH, Palma Dibb RG, Panzeri H, Lara EH, Dinelli W. Assessing the surface roughness of a posterior resin composite: effect of surface sealing. Oper Dent. 2003 May-Jun;28(3):281-6.
49. Nikawa H, Chen J, Hamada T, Nishimura M, Polyzois G. Candida albicans colonization on thermal

cycled maxillofacial polymeric materials in vitro. J Oral Rehabil. 2001 Jun;28(6):526-33.

50. Bürgers R, Schneider-Brachert W, Rosentritt M, Handel G, Hahnel S. Candida albicans adhesion to composite resin materials. Clin Oral Investig. 2009 Sep;13(3):293-9.

51. Huh JB, Lim Y, Youn HI, Chang BM, Lee JY, Shin SW. Effect of denture cleansers on Candida albicans biofilm formation over resilient liners. J Adv Prosthodont. 2014 Apr;6(2):109-14.

52. Dezelic T, Guggenheim B, Schmidlin PR. Multi-species biofilm formation on dental materials and an adhesive patch. Oral Health Prev Dent. 2009;7(1):47-53.

53. Song F, Koo H, Ren D. Effects of Material Properties on Bacterial Adhesion and Biofilm Formation. J Dent Res. 2015 Aug;94(8):1027-34.

54. Pereira CA, Eskelson E, Cavalli V, Liporoni PC, Jorge AO, do Rego MA. Streptococcus mutans biofilm adhesion on composite resin surfaces after different finishing and polishing techniques. Oper Dent 2011; 36: 311–317.

55. Pereira CA, Eskelson E, Cavalli V, Liporoni PC, Jorge AO, do Rego MA. Streptococcus mutans biofilm adhesion on composite resin surfaces after different finishing and polishing techniques. Oper Dent. 2011 May-Jun;36(3):311-7.

56. Tang H, Wang A, Liang X, Cao T, Salley SO, McAllister JP 3rd, et al. Effect of surface proteins on Staphylococcus epidermidis adhesion and colonization on silicone. Colloids Surf B Biointerfaces. 2006 Aug 1;51(1):16-24.

57. Gyo M, Nikaido T, Okada K, Yamauchi J, Tagami J, Matin K. Surface response of fluorine polymer-incorporated resin composites to cariogenic biofilm adherence. Appl Environ Microbiol. 2008 Mar;74(5):1428-35.

58. Imazato S. Antibacterial properties of resin composites and dentin bonding systems. Dent Mater. 2003 Sep;19(6):449-57.