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Efficiency of polymerization of bulk-fill composite resins: a systematic review

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Abstract: This systematic review assessed the literature to evaluate the efficiency of polymerization of bulk-fill composite resins at 4 mm restoration depth. PubMed, Cochrane, Scopus and Web of Science databases were searched with no restrictions on year, publication status, or article's language. Selection criteria included studies that evaluated bulk-fill composite resin when inserted in a minimum thickness of 4 mm, followed by curing according to the manufacturers' instructions; presented sound statistical data; and comparison with a control group and/or a reference measurement of quality of polymerization. The evidence level was evaluated by qualitative scoring system and classified as high-, moderate- and low- evidence level. A total of 534 articles were retrieved in the initial search. After the review process, only 10 full-text articles met the inclusion criteria. Most articles included (80%) were classified as high evidence level. Among several techniques, microhardness was the most frequently method performed by the studies included in this systematic review. Irrespective to the *"in vitro"* method performed, bulk fill RBCs were partially likely to fulfill the important requirement regarding properly curing in 4 mm of cavity depth measured by depth of cure and / or degree of conversion. In general, low viscosities BFCs performed better regarding polymerization efficiency compared to the high viscosities BFCs.

Keywords: Composite resins; Polymerization; Curing lights, Dental; Dentistry.

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Introduction

It is well known that resin based composites (RBCs) require a dry field, critical steps for enamel and dentin etching, priming, and bonding, and the maximum incremental thickness has historically been 2 mm. Still, restoring deeper preparations with 2-mm increments is time consuming and relatively technique sensitive.[1] The rationale behind the incremental filling technique is to guarantee the penetration of the curing light deeply enough to initiate and complete curing RBCs,[2] besides the minimization of the shrinkage and shrinkage-induced stress associated with polymerization of RBCs. Nevertheless, recently, manufacturers have introduced resin-based bulk-fill composites (BFCs), and it has been claimed that they can fill cavities up to 4–6 mm at once.[3,4,5,6]

Several bulk-fill composite materials are currently on the market, including low- and high-viscosity formulations (Table 1). Each BFC adopt different strategies for achieving high light transmission and flowability. A sufficient depth of cure may be achieved by using specific polymerization modulators, by improving the translucency, or by using more potent initiator systems.[7] Generally, low-viscosity BFCs present low filler content to increase flowability. However, some materials present high filler content, but achieve flowability through sonic activation (SonicFill).

Although bulk-filling technique increases light path length into the deep subsurface and resin volume by the increased cavity depth,[8] manufacturers of BFCs state that materials present greater depth of cure and lower polymerization induced shrinkage stress than conventional RBCs.[9] Low shrinkage stress can be reached through the inclusion of stress reliever (*e.g.* Tetric N-Ceram Bulk Fill, Tetric N-Flow Bulk Fill, Tetric EvoCeram Bulk Fill), polymerization modulator (*e.g.* SureFil SDR), or their own not disclosed ways to lessen high possible stress induced by the massive filling.[10,11] Still, regarding mechanical properties of the resin, it has been stated that the reduced filler content of BFCs for achieving high light transmission can weaken their mechanical properties compared with conventional RBCs.[12,13]

For a clinician to confidently change from using a traditional incremental filling technique to the bulk-filling method, credible clinical trials and laboratory studies comparing characteristics of the polymerization reaction at restoration depths that simulate the clinical scenario should be performed.[14] In order to assess the maximal increment thickness of resin composites that guarantee efficient polymerization, researchers have referred to depth of cure (DOC)[15,16,17] and degree of conversion (DC) measurements.[18,19] Current literature already provides DOC and DC data for several restorative bulk-fill materials.[15,16,17,18,20,21,22,23] Therefore, the aim of this systematic review was to assess the scientific literature that evaluated the efficiency of polymerization of bulk-fill composite resins by assessing DOC and DC to answer the clinical question: can Bulk-fill resin composites be placed and cured properly in 4 mm increments?

Methodology

This systematic review was performed according to the Cochrane Oral Health Group's Handbook for Systematic Reviews of Interventions (http://ohg.cochrane.org), and was registered with the number CRD42016047754 in the PROSPERO database (http://www.crd.york.ac.uk/PROSPERO). A computerized systematic search was performed in 4 electronic databases: PubMed, Cochrane, Scopus and ScienceDirect. For all the databases, the following search sequence of key words was

Table 1. Materials under investigation (information as disclosed by the manufacturers).

Bulk Fill Composites	Viscosities	Maximum depht	Time / Irradiance
EverX Posterior (GC)	Regular	4 mm	9-sec / Plasma arc (2000 mW/cm²); 10-sec / High Power LED Light (>1200 mW/cm²); 20-sec / Halogen - Normal LED Light (700 mW/cm²)
Filtek Bulk Fill (3M ESPE)	Regular	5 mm	20-sec / (>1000 mW/cm²)
Filtek Bulk Fill Flowable (3M ESPE)	Flow	4 mm	20-sec (>1000 mW/cm²)
QuiXX Fill (DENTSPLY)	Flow	4 mm	20-sec / (500-800 mW/cm²); 10-sec / (>800mW/cm²)
SonicFill (KERR)	Regular	5 mm	20-sec (>1000mW/cm²)
SureFil SDR (DENTSPLY)	Flow	4 mm	20-sec (U) or 40-sec (A1/A2/A3) / (>1000mW/cm²)
Tetric EvoCeram Bulk Fill (IVOCLAR)	Regular	4 mm	20-sec / (>500mW/cm²); 10-sec / (>1000mW/cm²)
Venus Bulk Fill (HERAEUS KULZER)	Regular	4 mm	20-sec / (>1000mW/cm²)
XTra Base (VOCO)	Flow	4 mm	10-sec / (> 1000mW/cm²)
XTra Fill (VOCO)	Regular	4 mm	10-sec / (> 1000mW/cm²)

selected: ["polymerization" AND "composite resins" AND ("bulk fill" OR "bulk-fill")]. No restrictions were placed on year, publication status, or language of the articles. The search was performed on September the 14th, 2016. Additional relevant studies published after this date were also included, although no formal searching was conducted after September 2016.

In the first step of the screening process, titles and abstracts were used to identify full articles as being relevant (or potentially relevant) that evaluated the efficiency of polymerization of bulk-fill composite resins by performing mechanical tests. The ones that evaluated physical properties related to efficiency of polymerization by thermal analysis were not considered relevant for this systematic review.

In the second step of the screening process, these full articles were subjected to inclusion and exclusion criteria. The inclusion criteria required studies in which the bulk-fill composite was used with a minimum thickness of 4 mm and cured following the manufacturers' instructions (regarding time and irradiance), the statistical data (such as the sample size, mean, and standard deviation) were provided in the results section, and a control group was used; such as comparison with a conventional composite resin, or a reference measurement of quality of polymerization (comparison between the polymerization data obtained at the top and at the bottom of the sample). The exclusion criteria were: case reports, case series, reviews, systematic reviews, opinions of experts, and reports provided by the manufacturing companies.

All studies identified by applying the inclusion and exclusion criteria underwent for validity assessment and data extraction by two reviewers (M.G.R and J.A.R) that independently examined the studies. The reviewers extracted data independently, using specifically designed data-extraction forms. For each included study, qualitative and quantitative information was extracted, including authors, year of publication, experimental and control group, type of bulk-fill composite resin (viscosity), number of samples per group, method of outcome assessment (mechanical test performed), polymerization protocol (time and irradiance), storage (time, temperature, and medium), authors' conclusions, and all information needed for methodological quality evaluation. Any disagreement was discussed to reach a common final decision. In case further clarifications were deemed necessary, the authors of the related papers were contacted by email.

Posteriorly, the two reviewers scored the remained articles, in order to analyze the study design and the methodological reliability, based on the mechanical test performed and on the degree of technical information available. Some scoring systems already published[24,25,26] were used as a starting point to develop the present methodological scoring system as shown in Table 2.

Concerning study design, different scores were given if the study compared the bulk-fill results with a conventional composite resin (control group) and/or based on hardness measurements on the top and the bottom surface of light-cured resin composite specimens (a bottom-to-top hardness ratio of 0.80 has been widely used as a criterion for adequate degree of cure). The sample size, and the mechanical testing performed to evaluate the efficiency of polymerization, based on the degree of conversion (DC) and/or the depth of cure (DOC), were also considered. Many laboratory methods have been used to determine these mechanical properties, such as Fourier transform infrared (FTIR) spectroscopy, Raman spectroscopy, Microhardness (Vickers and Knoop), Scraping Method ISO 4049, and Acetone Shaking Test. Studies that performed the Scraping Method ISO 4049 were evaluated with less points compared to the ones that performed the others available methods, since it has been shown that the former method overestimate depth of cure values.[16,27,28,29]

With respect to methodological soundness, the description of the light curing protocol (time, irradiance, and light-curing unit used to specimens' photoactivation) was evaluated, since a strong relationship exists between the light curing protocol and the mechanical properties of the composite resin.[30] In addition, the presence and the description of an aging evaluation (time, medium and temperature) were also considered. Timing of testing is also variable and represents an important factor to be taken into account in scientific investigations of bulk-fill

Table 2. Methodological scoring system.

Criteria assessed	Score
I. Study design (Maximum score = 11 points)	
A. Control group	Conventional resin based composite: 1 point Bottom:Top ratio: 2 points Both groups: 3 points
B. Sample size	Number of evaluated sample per experimental group (n): n < 5: 1 point 5 ≤ n ≤ 10: 2 points n > 10: 3 points
C. Experimental groups	High and low viscosities: 2 points High viscosity: 1 point Low viscosity: 1 point
D. Mechanical testing	Scraping ISO 4049 Method or Acetone Shake Test: 1 point FTIR, mRaman, Microhardness: 2 points If 2 or more methods were combined: 3 points
II. Methodological soundness (Maximum score = 8 points)	
A. Light curing protocol	If clearly described time, power density and LCU: 3 points (1 point each)
B. Aging evaluation	If clearly describe time, temperature and medium of storage: 2 points
C. Post-cure time evaluation	Immediate or less than 24 hours post-cure: 1 point 24 hours post-cure: 2 points more than 24-hours / cycling: 3 points

composites, since the DC changes over time and, therefore, differences in "post-cure" time introduce variability that might affect comparability of results reported in different studies.[21,31,32]

The methodological quality scores were reported as a percentage of the maximum achievable score (19 points): mean score (mS) < 60 percent = low level of evidence; 60 percent ≤ mS ≤ 70 percent = moderate level of evidence; mS > 70 percent = high level of evidence.[25,26]

Results

The database search revealed 534 articles: 169 articles listed in PubMed, 12 articles listed in Cochrane, 58 articles listed in Scopus, and 295 articles listed in Web of Science. Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram,[33] an overview of the article selection process is illustrated (Figure). After exclusion of 187 duplicate articles, 347 articles remained. In the first step of the screening process, 271 articles were excluded, since they did not evaluate efficiency of polymerization of bulk-fill composite resins by performing mechanical tests.

In the second step of the screening process, the remaining 76 full-text articles were assessed: 10 articles were excluded after the application of the exclusion criteria, and 56 articles were excluded, as they did not meet the inclusion criteria (Figure). Exceeding of the time recommended by the manufacturers was the most common methodology flaw found when the inclusion criteria were applied. Thus, the selection process resulted in 10 full-text articles.[3,10,16,18,34,35,36,37,38,39]

A summary of the main findings of each study addressed in this systematic review and the data regarding authors, year of publication, type of bulk-fill composite resin (viscosity), method of outcome assessment (mechanical test performed), light curing protocol (time, irradiance, and light-curing unit), and authors' conclusions regarding the clinical question "can Bulk-fill resin composites be placed and cured properly in 4 mm increments?" is presented in Table 3.

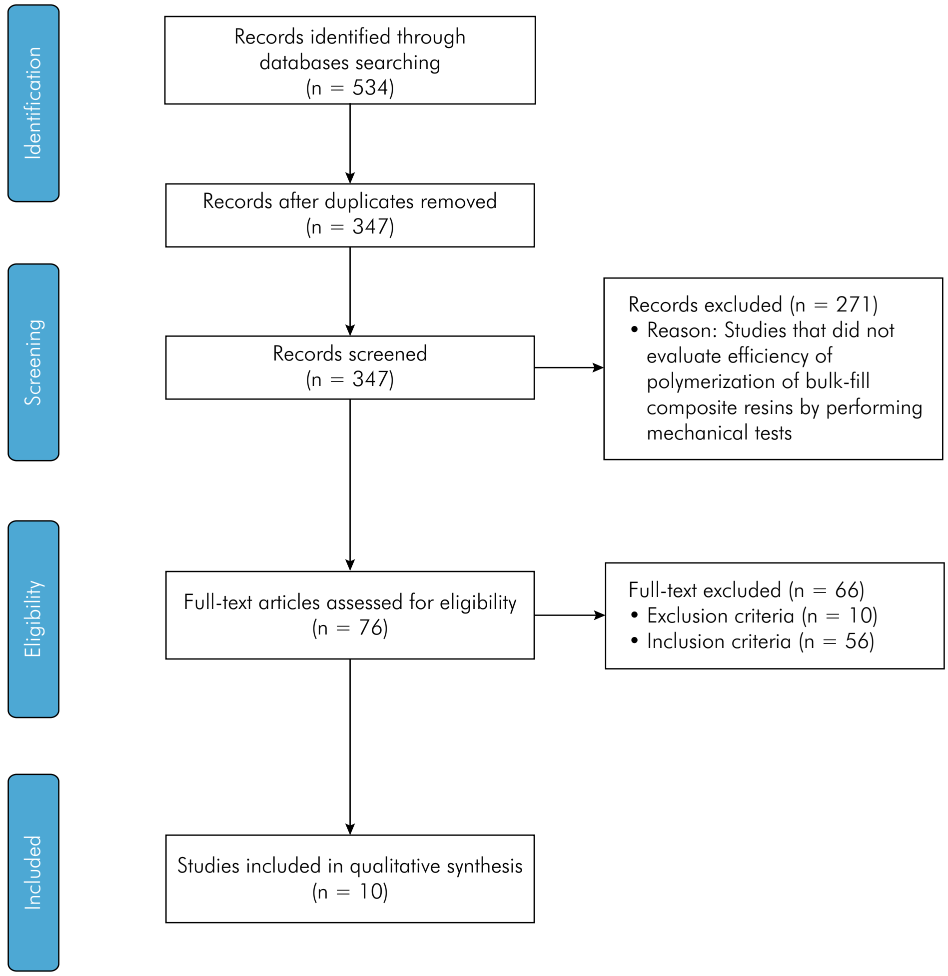

Figure. Flow diagram with an overview of the article-selection process.

None of the studies included were clinical trials. All the articles were published in English, between 2012 and 2016. Methodological quality scores ranged from 47% to 89% of the maximum achievable score, with a mean score of 76,8%. Eight studies were classified as high- (80%), 1 as moderate- (10%), and 1 as low- (10%) evidence level (Tables 4, 5 and 6). It was not possible to perform a meta-analysis because of the heterogeneous methodologies of the selected studies.

Many laboratory methods have been used to determine the efficiency of polymerization of restorative materials, based on the degree of conversion and depth of cure. The present systematic review included studies that degree of conversion and/ or depth of cure were assessed by Fourier transform infrared (FTIR) spectroscopy,[10,18,36,39] Micro-Raman spectroscopy,[35,38] Scraping Method ISO 4049,[3,16,34] Acetone Shaking Test,[36] and Microhardness.[10,16,18,34,36,37,39] Irrespective to the *"in vitro"* method performed, bulk fill RBCs were partially likely to fulfill the important requirement regarding properly curing in 4 mm of cavity depth measured by depth of cure and / or degree of conversion.

Discussion

In the last 5 years, numerous articles have been performed to investigate polymerization of resin-based bulk-fill composites. Despite the massive literature addressing this topic, only 10 studies were considered appropriate for inclusion in this systematic review. Based on the selection criteria, *in vivo* studies were not considered relevant, since they did not report the

Table 3. Main findings and data of the studies addressed in the systematic review.

Study	Bulk- fill composites	Viscosities	Mechanical test	Light curing protocol	Post-cure time evaluation	Can BFCs be placed and cured properly in 4 mm increments?
Benetti et al., 2015 [3]	Tetric EvoCeram Bulk Fill, SonicFill, x-tra base, Venus Bulk Fill, and SureFil SDR	High and low	Scrapping Method ISO 4049	20-sec; 950 ± 50 mW/cm^2; LED LCU	Immediate	PARTIALLY. With a mean depth of cure of 3.43 mm, SonicFill failed to comply the value stated by the manufacturer (up to 5-mm increments). Tetric EvoCeram Bulk Fill also showed a depth of cure slightly lower (3.82 mm) than the value advertised by its manufacturer (4 mm). However, the other investigated low-viscosity bulk-fill resin composites (SDR, Venus Bulk Fill, and x-tra base), demonstrated higher and sufficient depth of cure at more than 4 mm (4.34, 5.57, and 5.68, respectively).
Czasch and Ilie, 2013 [18]	SureFil SDR, and Venus Bulk Fill	Low	FTIR and Microhardness	10-, 20-, and 40-sec; 1,226 mW/cm^2; LED LCU (Elipar Freelight)	Microhardness (24 hours)	YES. Both RBCs may be placed in 4 mm bulks without a loss in mechanical properties or degree of cure. A polymerization time of 20 seconds and bulk placement up to 4 mm can be recommended.
Flury et al., 2012 [16]	SureFil SDR, Venus Bulk Fill, QuiXX Fill, Tetric EvoCeram Bulk Fill	High and low	Scrapping Method ISO 4049 and Microhardness	10- and 20- sec, 1000 mW/cm^2, LED LCU (Demi)	Immediate	PARTIALLY. The Scrapping Method showed that only Tetric EvoCeram Bulk Fill (light-cured for 10-sec according to the manufacturer indication) did not meet the ISO requirement (DOC = 3.32 mm). The percentage of VHN^{max} attained at the depth D^{ISO} was assessed and expressed as p^{ISO}. Whereas p^{ISO} was above 80% for one of the control materials (Filtek Silorane), p^{ISO} was much lower particularly for the bulk fill materials, which showed in the median a p^{ISO} of only 40%, reflecting the different forms of the VHN profiles.
Garcia et al., 2014 [34]	SureFil SDR, Venus Bulk Fill, and SonicFill	High and low	Scrapping Method ISO 4049 and Microhardness	20- sec, 800 mW/cm^2, LED LCU (SmartLite iQ2)	Microhardness (24 hours)	PARTIALLY. The Scrapping Method showed that only SonicFill could not be cured properly in 4 mm (DOC = 3.46 mm), while both Venus Bulk Fill and SureFil SDR flow demonstrated full depth of cure at 5 mm. Regarding microhardness values, all bottom:top ratio values for the materials evaluated in this study were less than the 80% critical value for depth of cure.
Ilie et al., 2013 [10]	Tetric EvoCeram Bulk Fill and x-tra base	High	FTIR and Microhardness	10-, 20-, and 40-sec; 1.703 mW/cm^2 (0 mm distance) and 500 mW/cm^2 (7 mm distance from the particular mould); LED LCU (Elipar Freelight2)	Microhardness (24 hours)	YES. The results of the study proved that both analyzed bulk-fill materials – Tetric EvoCeram Bulk Fill and x-tra base – enable, as described by the manufacturer, at least 4 mm thick increments to be cured in one step under clinically relevant curing conditions.

Continue

Continuation

Lempel et al., 2016 [35]	SureFil SDR, X-tra Base, Filtek Bulk Fill	Low	Micro-Raman Spectroscopy	10- (X-tra Base) and 20-sec (Filtek Bulk Fill and SureFil SDR) ; 1100 mW/cm^2 ; LED LCU (LED.C)	24 hours	PARTIALLY. SDR showed the highest DC value at the top and bottom surface of the samples and not significant lower %DC compared to 0 mm. X-tra Base and Filtek Bulk Fill presented about 35% lower DC compared to the top.
Miletic et al., 2016 [36]	Tetric EvoCeram Bulk Fill, SonicFill, SureFil SDR, EverX Posterior, and Filtek Bulk Fill flowable	High and low	FTIR, Acetone-Shaking Test, and Microhardness	10- and 20-sec; 1337 mW/cm^2; polywave LED LUC (Bluephase 20i)	FTIR and Microhardness (24 hours)	PARTIALLY. Tetric EvoCeram Bulk, EverX Posterior, and SonicFill, bulk-filled as 4-mm-thick specimens, showed bottom-to-top hardness ratios above 80 % after 20-sec curing. Still, 10-sec curing time was sufficient for flowable bulk-fills (SureFil SDR and Filtek Bulk Fill flowable).
Nagi et al., 2015 [37]	Tetric EvoCeram, and X-traFil	High and low	Microhardness	10-, 20-, 40-, and 60-sec; ≥ 800 mW/cm^2; LED LCU (Elipar S10)	24 hours	YES. The bulk-fill resin composites used in this study can be placed and cured properly in the 4 mm bulk. A short curing time 10 seconds was enough to reach VHN (bottom to top) ratio >80 % when both tested bulk fill RBCs are placed in 4 mm bulks.
Pongprueksa et al., 2015 [38]	Filtek Bulk Fill flowable	Low	Micro-Raman Spectroscopy	20-sec; 1100 mW/cm^2; polywave LED LUC (Bluephase 20i)	Immediate	YES. The cure at depth is considered adequate if DC measured at the bottom reaches at least 90% of the maximum DC measured at the top surface. Strictly applying this guideline, an adequate cure at 4-mm depth was achieved by the flowable bulk-fill composite (Filtek Bulk Fill Flowable: 92%).
Zorzin et al., 2015 [39]	Filtek BulkFill, SureFil SDR, TetricEvoCeram BulkFill, Venus BulkFill, and X-traBase	High and low	FTIR and Microhardness	10-, 20-, and 30-sec; 1200 mW/cm^2; polywave LED LUC (Bluephase 20i)	24 hours	PARTIALLY. All investigated bulk-fills had sufficient polymerization properties at 4 mm increment thickness in terms of not significant lower %DC compared to 0 mm. Still, when the 80% bottom-top-ratio criterion was applied as a minimum acceptable threshold, all investigated materials, with exception of TBF and FSF in the manufacturers' light-curing time (TBF 10 s, FSF 20 s at 1200 mW/cm2), showed adequate hardness at 4 mm. At higher radiant exposure (30 s at 1200 mW/cm^2) all materials reached at least 80% bottom-top-ratio.

BFCs:– bulk fill composites; LED: light emitting-diode; LCU: light curing unit; FTIR: Fourier transform infrared spectrometer; VHN: Vickers Hardness; DOC:depth of cure; DC: degree of conversion.

Table 4. Quality assessment scores concerning study design: study design (maximum score = 11 points).

Articles	Control group	Sample size	Experimental groups	Mechanical test	Score
Benetti et al.,[3] 2015	1	1	2	1	5
Czasch and Ilie,[18] 2013	2	2	1	3	8
Flury et al.[16], 2012	3	3	2	3	11
Garcia et al.,[34] 2014	3	2	2	3	10
Ilie et al.,[10] 2013	2	2	1	3	8
Lempel et al.,[35] 2016	3	2	2	2	9
Miletic et al.,[36] 2016	3	2	2	3	10
Nagi et al.,[37] 2015	2	2	2	2	8
Pongprueksa et al.,[38] 2015	3	2	1	2	8
Zorzin et al.,[39] 2015	3	2	2	3	10

Table 5. Quality assessment scores concerning study design: methodological soundness (maximum score = 8 points).

Articles	Light curing protocol	Aging evaluation	Post-cure time evaluation	Score
Benetti et al.,[3] 2015	3	0	1	4
Czasch and Ilie,[18] 2013	3	2	2	7
Flury et al.[16], 2012	3	0	1	4
Garcia et al.,[34] 2014	3	2	2	7
Ilie et al.,[10] 2013	3	2	2	7
Lempel et al.,[35] 2016	3	0	2	5
Miletic et al.,[36] 2016	3	2	2	7
Nagi et al.,[37] 2015	3	2	2	7
Pongprueksa et al.,[38] 2015	3	0	1	4
Zorzin et al.,[39] 2015	3	2	2	7

Table 6. Quality assessment scores concerning study design: classification of the evidence level (maximum score = 19 points).

Articles	Study design	Methodological soundness	% Score	Classification
Benetti et al.,[3] 2015	5	4	47%	Low
Czasch and Ilie,[18] 2013	8	7	79%	High
Flury et al.[16], 2012	11	4	79%	High
Garcia et al.,[34] 2014	10	7	89%	High
Ilie et al.,[10] 2013	8	7	79%	High
Lempel et al.,[35] 2016	9	5	74%	High
Miletic et al.,[36] 2016	10	7	89%	High
Nagi et al.,[37] 2015	8	7	79%	High
Pongprueksa et al.,[38] 2015	8	4	63%	Moderate
Zorzin et al.,[39] 2015	10	7	89%	High

parameters necessary to be included. A significant number of the excluded *in vitro* studies did not perform the curing protocol according to the manufactures' instructions (regarding time and irradiance), by exceeding the recommended time, which was the most common flaw detected. Laboratory studies should simulate as faithful as possible the clinical scenario, and clinicians undoubtedly simplify the restorative procedure aiming to save clinical time and, therefore, normally do not perform polymerization of restorations exceeding the time recommended by the manufacturers. Based on this scenario, these studies were not considered relevant to be included in this systematic review. A meta-analysis could not be made because of the heterogeneity of the study designs and methodologies.

The current literature already evidenced that several parameters may affect the degree of polymerization of bulk fill RBCs such as their composition (photoinitiators, fillers and organic matrix),[40] the technical characteristics of the light-curing unit (light intensity, thermal emission, wave length range, diameter of the tip) and the conditions of photo-polymerization (curing mode and exposure time),[41] the post-irradiation period,[42] the temperature,[43,44] and the incremental thickness of the material.[45] Therefore, the articles were scored in order to analyze the study design and the methodological reliability, based on the mechanical test performed and on the degree of technical information available. Relative to the methodological quality assessment, most studies included in this systematic review (80%) were classified as high evidence level.

Among several techniques, microhardness was the most frequently method performed by the studies included in this systematic review. Seventy percent of them used this method,[10,16,18,34,36,37,39] being in 60% combined with another methodology (such as FTIR, Acetone-Shaking Test, or Scrapping Method ISO 4049). Measuring the hardness has been already proved to be the best indicator of the extent of polymerization of the RBC.[46] It has been used as an indirect method to assess the depth of cure with a value of 80% of hardness at the top surface considered as the borderline between sufficient and insufficient curing.[16,23,29,46,47] Although the methods based on vibrational spectroscopy are considered more accurate because they directly quantify the amount of unreacted C=C bonds,[48] when the network is crosslinked, FTIR is less sensitive than hardness assessment in detecting small changes in the degree of conversion.[46] The degree of conversion of resin composites is widely evaluated indirectly by surface hardness measurements; both Vickers or Knoop indenters can give a reliable determination.[49]

Fourier transform infrared (FTIR) spectroscopy has been traditionally used for degree of conversion assessment and it was performed in 4 studies included in this systematic review.[10,18,36,39] Raman spectroscopy provides an alternative method that can be considered simpler and more adaptive than FTIR[50] and it was performed in 2 studies included in this systematic review.[35,38] While FTIR spectroscopy measures the absorption of incident radiation, Raman is based on the inelastic scattering phenomenon. In contrast to FTIR, mRaman does not require specific specimen preparation and allows a non-destructive analysis, which enables multiple measurements on the same sample.[50]

The Scraping Method ISO 4049 for bulk-fill composites has been researched and its suitability has been recently criticized for providing overestimation of the depth of cure values in comparison with Vickers hardness profiles.[16,27,29] In addition, the procedure of scraping off the uncured resin-based material has been considered difficult to standardize.[51] Still, this systematic review included 3 articles that used the Scrapping Method to evaluate depth of cure of bulk-fill composites[3,16,34] and, when performed in combination with hardness test, it was also verified overestimated values of the depth of cure in comparison with the hardness profiles.[16,34]

One study included in the present review performed the Acetone Shake Method to measure depth of cure.[36] This method involves physical removal of the unreacted monomers and has been performed to evaluate DOC by some researchers.[52,53,54] After curing, the resin composite specimen is placed into a hermetically sealed capsule containing 99.9 per cent pure acetone. The vibration of the capsule on a mixing device removed the uncured material in a reproducible manner,[52] leaving the polymerized portion undamaged.

Bulk fill RBCs were partially likely to fulfill the important requirement regarding properly curing in 4 mm of cavity depth measured by depth of cure and / or degree of conversion. In six studies, this statement was partially accepted,[3,16,34,35,36,39] and it is important to emphasize that the requirement was partially accepted because of the behavior of the regular viscosity BFC evaluated. In the remaining 4 studies included in the present systematic review this statement was completely accepted.[10,18,37,38] The results presented in this systematic review are exclusively based on *"in vitro"* studies. Still, in recent randomized controlled trials, bulk-fill technique showed highly clinical effectiveness, which was comparable with the conventional incremental technique during 5-year evaluation period.[55,56,57]

Although several issues may affect the polymerization efficiency of bulk fill composite resins, the composition and filler loading of the BFCs seem to be the most important factors. The variability on the conclusion of the authors was mainly dependent on the bulk fill composite resin evaluated, and, in general, the low-viscosity BFCs performed better regarding polymerization efficiency (with only 2 studies demonstrating bottom:top ratio values less than the 80% critical value for depth of cure[16,34]) compared to the high-viscosity BFCs.

Conclusions

High level of evidence is available to study the polymerization efficiency of bulk fill composites. BFCs were partially likely to fulfill the important requirement regarding being properly cured in 4 mm of cavity depth measured by depth of cure and / or degree of conversion. In general, low-viscosity BFCs performed better regarding polymerization efficiency compared to the high-viscosity BFCs, since only 2 studies that evaluated low viscosity BFCs demonstrated bottom:top ratio values less than the 80% critical value for depth of cure.

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