Japanese Dental Science Review 59 (2023) 239–252

Contents lists available at ScienceDirect

Japanese Dental Science Review

journal homepage: www.elsevier.com/locate/jdsr

Effect of nanofibers as reinforcement on resin-based dental materials: A systematic review of in vitro studies☆

Laís Santos Albergaria [a], Cassiana Koch Scotti [a], Rafael Francisco Lia Mondelli [a], Heber Arbildo Vega [b,c], Clovis Mariano Faggion Jr [d], Juliana Fraga Soares Bombonatti [a], Marilia Mattar de Amoêdo Campos Velo [a,*]

[a] *Department of Operative Dentistry, Endodontics, and Dental Materials, Bauru School of Dentistry, University of São Paulo, Bauru, São Paulo, Brazil*
[b] *Faculty of Dentistry, Department of General Dentistry, San Martín de Porres University, Chiclayo, Peru*
[c] *Faculty of Human Medicine, Department of Human Medicine, San Martín de Porres University, Chiclayo, Peru*
[d] *Department of Periodontology and Operative Dentistry, Faculty of Dentistry, University Hospital Münster, Münster, Germany*

ARTICLE INFO

Keywords:
Bisphenol A Glycidyl Methacrylate
Dental materials
Nanofibers
Resin composite

ABSTRACT

This systematic review provides an update on the effect of nanofibers as reinforcement on resin-based dental materials. A bibliographic search was conducted in MEDLINEPubMed, Embase, Web of Science, Scopus, BVS (LILACS, BBO e IBECS), Cochrane, LIVIVO, and gray literature (BDTD) to identify relevant articles up to May 2021. In vitro studies that evaluated and compared the mechanical properties of nanofibers resin-based composite materials, were eligible. No publication year or language restriction was applied, and methodological quality was assessed using two methods. In a total of 6100 potentially eligible studies, 81 were selected for full-text analysis and 35 were included for qualitative analysis. Of the 35 included studies, a total of 29 studies evaluated the flexural strength (FS) of the materials. These groups were distinguished according to the resin-based materials tested and nanofiber types. Most of the studies evaluated materials composed of glass fibers and demonstrated higher values of FS when compared to resin-based materials without nanofibers. The incorporation of nanofibers into resin-based dental materials improved the mechanical properties compared to resin-based materials without nanofibers, suggesting better performance of these materials in high-stressbearing application areas. Further clinical studies are required to confirm the efficacy of resin-based materials with nanofibers.

1. Introduction

Dental composites or resin-based composites combine a polymeric matrix with a dispersion of glass, minerals, filler particles, or short fibers through coupling agents. They are often used as synthetic materials to restore tooth structure lost through trauma, caries, and erosion, or used as resin cements to cement crowns, posts, and veneers [1]. Although resin-based composites have become widely used in restorative dentistry, and even with their significant improvement over time, they still present some shortcomings. The main goal is to develop a material with reduced polymerization shrinkage and sufficient depth of cure or degree of conversion (DC) along with great mechanical properties and esthetics [2]. However, in the case of restorative composites, for instance, they are limited by deficiencies in mechanical strength and high polymerization shrinkage, which are responsible for secondary caries, fracture, and the shorter median survival life of this material when compared to amalgam [3–5].

Since the introduction of resin composites more than 50 years ago [6], the predominant monomer used in the organic matrix has been the 2,2-bis- [4- (methacryloxypropoxy) -phenyl] -propane (Bis-GMA), and various inorganic fillers have been used as reinforcement to achieve better properties of resin-based dental materials. Owing to the fact that inorganic fillers are harder than the organic matrix, the stress that occurs during chewing is transmitted through these particles, promoting fractures and, consequently, weakening the resinous matrix [7]. Therefore, some efforts have been made to reinforce resin-based dental materials

☆ Scientific field of dental Science: Biomaterials.

* Correspondence to: Department of Operative Dentistry, Endodontics, and Dental Materials, Bauru School of Dentistry, University of São Paulo, Al. Dr. Otávio Pinheiro Brisolla 9-75 Vila Universitária, Bauru CEP: 17012-901, SP, Brazil.
E-mail address: mariliavelo@usp.br (M.M.A.C. Velo).

https://doi.org/10.1016/j.jdsr.2023.07.002
Received 10 August 2022; Received in revised form 16 April 2023; Accepted 12 July 2023
Available online 4 August 2023

with nanostructures to enhance their mechanical properties, including ceramic whiskers [8], carbon nanotubes [9,10], TiO_2 nanotubes [11], organic nanofibers [12–14] and, more recently, hybrid inorganic-organic nanofibers [15,16].

Fiber-reinforced resin composites have been shown to promote an increase in the strength and toughness of the filler-resin network [17–22] due to their reduced diameter. Unlike the fillers, nanofibers are distributed and aligned [14,23,24]; therefore, if a microcrack is initiated in the matrix due to masticatory stress, the reinforced matrix remains intact across the crack, thus supporting the applied load. The effect of the fiber fillers as reinforcement also strongly depends upon the stress transfer from the polymer matrix to fibers, often achieved by the use of coupling agents which chemically bond the inorganic filler materials to the organic resin matrix [25]. However, such reinforcement effectiveness is dependent of some variables, such as the type of resin, the quantity of fibers in the resin matrix, adhesion of fibers to the polymer matrix and length of fibers [24].

Although the incorporation of nanofibers into resin-based composites seems to be a promising reinforcement strategy, there is a lack of agreement since this particularly involves different types of nanofibers and distinct methodologies to evaluate it. When polyacrylonitrile nanofiber mats were incorporated into methacrylate resin blends, a significant improvement in tensile properties was reported [13]. The same was previously observed by incorporating nylon 66 nanofibers into dental composites [26], demonstrating that FS, flexural modulus (E), work of fracture (WOF), and hardness (H) of the resin composites were improved significantly in comparison with the resin control. The incorporation of hybrid nanofibers (composed of organic and inorganic phases) in resin-based composites has also gained attention as a promising strategy for improving both mechanical properties and bioactivity, since they act as a template for the release of therapeutic ions, such as niobium, fluoride, calcium phosphate, or silica nanoparticles [15,16]. Such structures can even be 3D-printed, which is a promising emerging technique in Dentistry to fabricate dental restorative materials [27,28].

In general, the literature discusses the role of nanofibers in the mechanical behavior of experimental resin-based composites. Nonetheless, some fiber-reinforced resin composites have been introduced into the marketplace and need more elucidation regarding their mechanical properties, as they are usually applied in high-stress bearing areas and frequently exposed to masticatory forces [29]. A previous study showed that a short fiber-reinforced resin composite for direct restorations exhibited improvements in the overall mechanical properties, showing that it could perform better performance in high stress-bearing restorative situations when compared to resin composites with a conventional type of filler [30]. Conversely, Yancey et al. [31] demonstrated that a commercial nanofiber-reinforced hybrid composite presented similar FS, shrinkage, and DC, but significantly greater depth of cure and E when compared to traditional hybrid resin composites. In this reported study, the authors suggested that there is no advantage in using this nanofiber composite restorative material when compared to the use of traditional hybrid composites [31].

Therefore, it would be reasonable to verify their real effect on the mechanical properties of resin-based composites. In addition, it seems that there is a limit to the amount of nanofiber content according to the weight until mechanical properties decrease [21,32], and a large mass of nanofibers impregnation could not improve mechanical properties, but could even reduce it [7]. Although there are a significant number of *in vitro* studies that evaluated resin-based composites reinforced with nanofibers, they suggest a comparison of the results obtained, which will guide future research and the development of a resin composite with better mechanical properties. Therefore, a proper elucidation of the performance of this relatively new class of materials is required.

However, most studies used different types of nanofibers to evaluate their mechanical behavior. Taking into account the related disagreement in the literature and owing to the relatively recent introduction of fiber-reinforced resin products into the market, an appropriate systematic review is a tool that will gather information in a decision-making process. Thus, the current study aimed to evaluate the available scientific evidence through an *in vitro* systematic review of the literature regarding the effect of nanofibers on the mechanical behavior of resin-based dental materials.

2. Materials and methods

The present systematic review was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [33,34] and registered in the PROSPERO (CRD42020190191).

To prepare and structure this review, the focused question was elaborated using the PICO format (population, intervention, comparison, and results) as detailed below:

- Population: Resin-based dental materials.
- Intervention: Resin-based dental materials with nanofibers according to different types and sizes.
- Comparison: Conventional resin-based dental materials.
- Outcomes: Mechanical strength.

The research question was: "Do resin-based dental materials with nanofibers have more mechanical strength than conventional resin-based materials?".

2.1. Search strategy

A bibliographic search was conducted in MEDLINE-PubMed, Embase, Web of Science, Scopus, BVS (LILACS, BBO e IBECS), Cochrane, LIVIVO, and gray literature (BDTD) to identify relevant articles published up to May 21, 2021, with no limitations on the language or year of publication. Vocabulary (MeSH terms in PubMed and Emtree terms in Embase) and free-text terms were used, defining the search strategies with keywords based on each section of the PICO question, separated by the Boolean operator OR and combined using the Boolean operator AND.

The definitions in the field of nanotechnology consider nanomaterials materials that are typically but not exclusively below 100 nm in at least one dimension [33,34], where the length can exceed diameter by 100-times [34]. Broadly, the scope of nanofibers includes fibers with diameter below one µm [34,35]. Since the specific definition of nanofibers is variable, such definition in the current review was wide in order to include comprehensive literature. Table 1 represents the search strategy of this study.

2.2. Eligibility criteria

2.2.1. Inclusion criteria

All *in vitro* studies that evaluated and compared mechanical properties by direct testing of nanofibers resin-based composite materials, including the basic chemical composition groups of methacrylates, were

Table 1
Search strategy performed for MEDLINE-PubMed duly modified for the other databases.

Search strategy	("composite resin"[All Fields] OR "composite resins"[All Fields] OR "resin composite"[All Fields] OR "resin composites"[All Fields] OR "composite"[All Fields] OR "composites"[All Fields]) AND ("fibre"[All Fields] OR "fibres"[All Fields] OR "fiber"[All Fields] OR "fibers"[All Fields] OR "nanofibre"[All Fields] OR "nanofibres"[All Fields] OR "nano fibre"[All Fields] OR "nano fibres"[All Fields] OR "nanofiber"[All Fields] OR "nanofibers"[All Fields] OR "nano fiber"[All Fields] OR "nano fibers"[All Fields]) AND ("dental"[All Fields] AND ("material"[All Fields] OR "materials"[All Fields]) OR "Bisphenol A Glycidyl Methacrylate"[All Fields] OR "Bis phenol A Glycidyl Methacrylate"[All Fields] OR "Bis GMA"[All Fields])

included in the review.

Direct methods to evaluate the mechanical properties considered in this study were: FS, E, H, fracture toughness (FT), compression strength (CS), biaxial flexural strength (BFS), energy at break (EAB), and diametral tensile strength (DTS).

2.2.2. Exclusion criteria

Systematic and literature reviews, case reports, case series, opinions of experts, meeting abstracts, editorials, and studies without a control group. Studies that focused on modified fibers surface were not considered relevant for this systematic review.

2.3. Study selection

In the first step of the screening process, titles and abstracts were used to identify potentially relevant full articles that evaluated the mechanical properties of resin-based composites filled with nanofibers by performing mechanical tests. In the second step of the screening process, all selected papers were screened using the inclusion and exclusion criteria. All studies were selected by two reviewers (L.S.A. and C.K.S.) that independently examined the studies. In the event of any doubt, a third reviewer (M.M.A.C.V) was consulted, and an agreement was reached.

2.4. Data extraction

Two reviewers (L.S.A. and C.K.S.) extracted data independently using specifically designed data extraction forms, which included: first authors, year of publication, country/continent of the first author, journal type, number of citations, dental discipline, number of authors, experimental and control group, type of nanofiber used, length of nanofiber, method of outcome assessment (mechanical test performed), outcomes of each tests, polymerization protocol (time and irradiance), sample size calculation, funding source, declarations/conflict of interest, and key conclusions of the study authors. Again, in case of disagreement, a third reviewer (M.M.A.C.V) was consulted.

2.5. Quality assessment

The methodological quality of the studies was assessed by two reviewers (L.S.A. and H.V.) independently, following an *in vitro* protocol [36,37]. It was verified whether the mechanical properties were analyzed in accordance with the following parameters: samples obtained through a standardized process; single operator of the machine; sample size calculation; blinding of the testing machine operator, sample size calibration before applying the test, test design, and calculations in accordance with standards and specifications. If the study reported clearly on the parameter, it received a score of 0 for that specific parameter; if a particular parameter was reported but insufficiently or was unclear, the score attributed was 1; and if it was not possible to find this information, the score attributed was 2.

Other aspects also were observed to evaluate the methodological quality of the studies according to Faggion Jr. [38] as following: background and objectives, intervention, outcomes, sample size, randomization, allocation concealment mechanism, implementation, blinding, statistical methods, outcomes and estimation, limitations, funding, and protocol. If the authors reported the parameter, the study received a "YES" for that specific parameter; partially answered received a "P.A."; otherwise, if it was not possible to find the information, it received a "NO".

3. Results

3.1. Search and selection

The PRISMA statement flowchart summarizing the selection process is shown in Fig. 1. A total of 6100 studies were identified through nine databases. Of these, 2491 duplicates were excluded and 3526 studies were excluded because they did not meet the eligibility criteria. The remaining 81 studies were selected for full-text examination. After the full texts were examined, 46 studies were excluded based on the eligibility criteria, and the remaining 35 studies qualified for descriptive analyses. The agreement between reviewers on quality assessments was high (Kappa = 0.932). Fig. 1 presents the flow of the study-selection process.

3.2. Effect of nanofibers on the mechanical behavior of resin-based dental materials

Of the 35 included studies, 29 evaluated the FS of the materials (Table 2). These groups were distinguished according to the resin-based materials tested and nanofiber types. In general, most of these studies evaluated materials containing glass fibers, and 9 of the 29 studies showed higher values of FS for resin-based materials reinforced with nanofibers. The incorporation of the nylon 66 nanofiber also improved the mechanical properties of dental resin composites, although it was observed that larger mass fractions of nylon 66 nanofibers were less desired.

Table 3 presents the overall main conclusions of all included studies related to the mechanical properties evaluated. A total of 8 studies evaluated commercial resin-based materials, most of them being commercial resin composites. In general, the commercial resin composites composed by E-glass fibers (everX-posterior and everX-flow) revealed improvements in mechanical properties compared with the conventional restorative composites. Only 1 study evaluated the effect of inorganic-organic hybrid fibers [15], concluding that this type of nanofiber is a potential reinforcing agent for resin cements. Only 1 study demonstrated significantly lower FS values of the commercial resin reinforced with nanofibers [31]. In this study, the authors suggested that the commercial resin composite NovaPro Fill, composed by calcium-phosphate (hydroxyapatite) nanofibers, may not be of any significant advantage to the use when compared to the use of traditional hybrid resin composites (Tables 2 and 3).

3.3. Methodological quality assessment

The methodological quality assessment was performed in all of the 35 studies included in the systematic review via two methods. The outcome of the methodological quality analysis is presented in Tables 4 and 5, showing moderate methodological quality. All 35 studies clearly reported that the samples were obtained through a standardized process, with the specimens, tests, and formulas following standard specifications. The most common limitations that were identified with both methods and were not reported or partially reported were the sample size calculation, random allocation sequence, and blinding of the testing machine. High heterogeneity was observed among the included studies in terms of the study design, methodology, and results. Therefore, a quantitative statistical meta-analysis was not conducted in this study, and a qualitative and descriptive analysis was performed for the collected data. The heterogeneity in the reported results could be due to the differences in the type of nanofibers, mass fractions of nanofibers incorporated into the material, different types of resin-based materials studied (i.e., resin composites or resin cements), length of the nanofibers, methods used to evaluate the mechanical properties, and the composition of the material tested (commercial or experimental resin-based materials that differ in terms of the monomer composition and inorganic fillers).

4. Discussion

Although several *in vitro* studies have evaluated the effect of nanofibers as reinforcement for resin-based materials and the efforts of

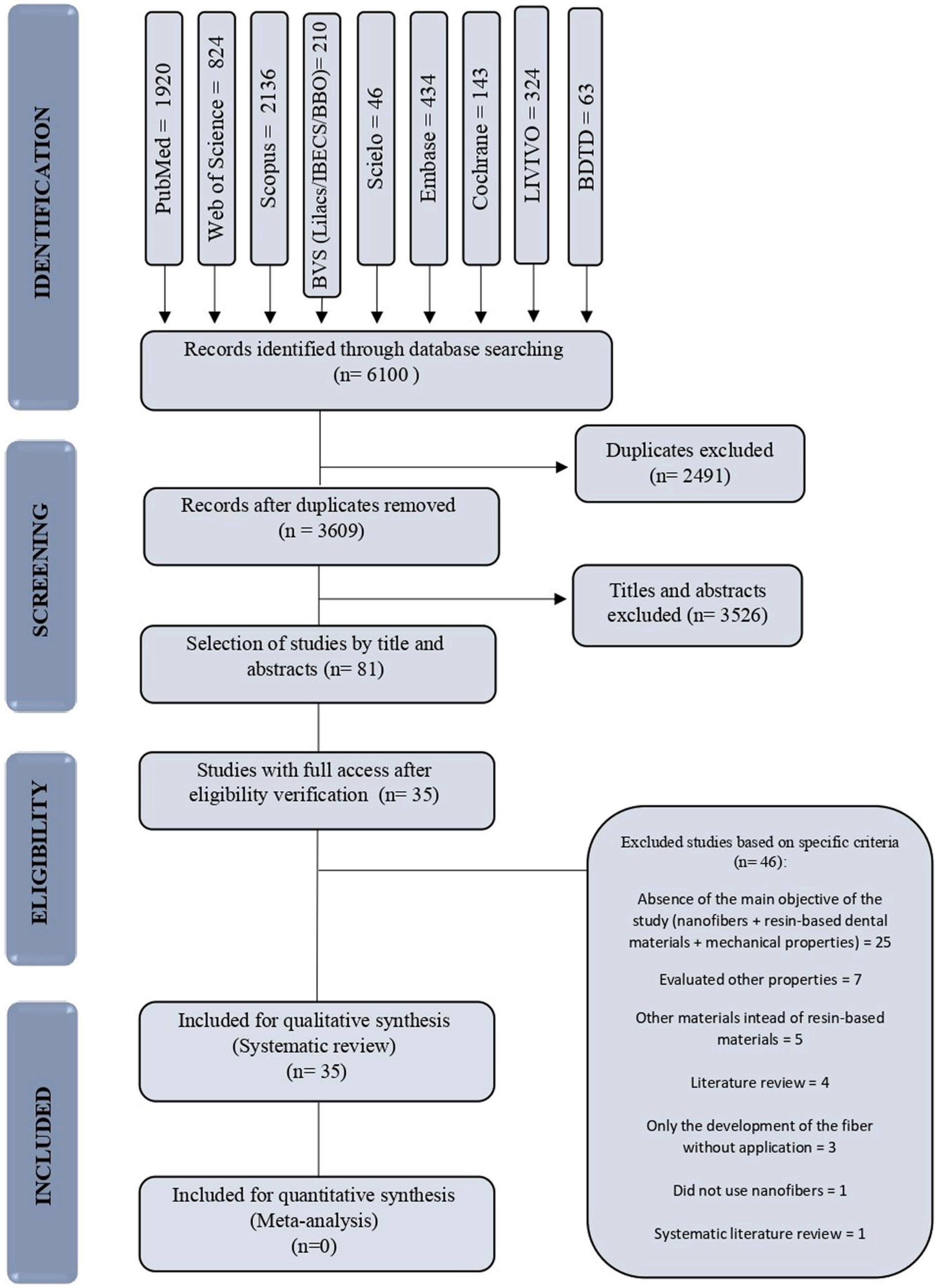

Fig. 1. Flowchart of study selection.

manufacturers to develop new fiber-resin composites, the doubt still remains whether clinicians should use this new class of resin composites. The vast majority of the studies included in this review indicated that incorporating nanofibers into resin-based dental materials had a positive effect on their mechanical properties. Improvements in the mechanical properties of dental composites are a requirement for the long-term success of restorations in clinical dentistry [14], and to overcome some drawbacks such as abrasion, breakdown, and secondary caries associated with the failure of restorations [39]. Table 3 shows that there is an improvement in the overall mechanical properties of resin-based composites with the incorporation of nanofibers.

It is important to note that in relation to the mechanical results, it is difficult to establish a direct comparison between the reinforcement types of nanofibers used so far since each study has a distinct design using different types of nanofibers, volume fraction, and methodologies. The decision to include studies that employed only direct methods to evaluate the mechanical properties was made mainly because they were the most widely used methods in the studies included. The direct methods evaluated were the FS, E, FT, H, CS, BFS, EAB, and DTS.

The mechanism proposed to explain the reinforcement that occurred by virtue of the incorporation of fibers is that when a microcrack is initiated into the organic matrix due masticatory stress and/or other forms of stress, the fibrillar fillers remain intact across the crack planes and support the applied load, working like a “stopper” of the crack resisted by the fillers and the matrix reinforced by fibers [7]. In general, fractures associated with the mechanical properties have been usually evaluated by the determination of FT, FS, and E. According to most authors of this review, the incorporation of nanofibers into resin-based composites presented high mechanical properties, especially FS and E (Table 3), that were important parameters for evaluating the mechanical

Table 2
Main results of flexural strength (FS) values (MPa) of the included studies.

Author, year	Resin-based material and comparisons	Nanofiber type	Flexural strength values (Mean ±SD)
Jafarnia et al. (2021)	(1) EverX Posterior; (2) Beautiful Bulk; (3) Filtek Bulk Fill	Short e-glass fiber	(1)145 ± 12.0; (2) 114.4 ± 14.1; (3) 167.5 ± 15.7.
Behl et al. (2020)	(1) Fiber-reinforced composite (FRC)− 1 to FRC-3 reinforced with 50 AR fibres, (2) FRC-4 to FRC-6 reinforced with 70 AR fibres, (3) FRC-7 to FRC-9 reinforced with 100 AR fibres	S-Glass fibres	Groups with 50/70 AR fibres (FRC-1–4 and FRC-6) showed significantly higher ($p < 0.05$) flexural strength as compared to PFC. FRC-2 containing 10% of 50 AR fibres presented the highest values (146.63)
Djustiana et al. (2020)	(1) dental composite reinforced with polymethyl methacrylate (PMMA)-silica nanofibers (1 wt% of silica content) (2) PMMA nanofiber as a control.	(1) PMMA-silica nanofiber and (2) PMMA nanofiber	(1)132.74 ± 20.70; (2) 128.99 ± 12.60
Lassila et al. (2020)	(1) Alert; (2) NovaPro Flow; (3) NovaPro Fill; (4) EverX Flow; (5) EverX Posterior	(1) Silica and micrometer scale glass fiber (2) nanometer scale hydroxyapatite fiber, (3) nanometer scale hydroxyapatite fiber, (4) micrometer scale glass fiber filler, (5) millimetre scale glass fiber filler.	(1)118 ± 18; (2)108 ± 12; (3)141 ± 17; (4)147 ± 23; (5)120 ± 5.
Suzaki et al. (2020)	(1) TRINIA longitudinal glass fiber; (2) TRINIA longitudinal-rotated glass fiber; (3) TRINIA anti-longitudinal glass fiber; (4) EverX posterior and (5) Beauti core flow paste	E-glass fibers	(1)254.2 ± 22.3; (2) 248.8 ± 16.7; (3) 96.9 ± 2.9; (4)98.0 ± 15.9 and (5)96.8 ± 3.3
Lassila et al. (2019)	(1) Surefil SDR; (2) Filtek bulk-fill flowable; (3) Tetric Evoflow bulk-fill; (4) Estelite bulk-fill flow; (5) Short fiber flowable composite	Short glass fiber	(1)120 ± 9.8; (2)122 ± 3.3; (3)97 ± 13; (4)133 ± 13; (5)146.5 ± 23
Borges et al. (2019)	(1) N6/2.5%; (2) N6/5.0%; (3) N6/10.0%; (4) N6/20.0%; (5) N6-MWCN/2.5%; (6) N6-MWCN/5.0%; (7) N6-MWCN/10.0%; (8) N6-MWCN/20.0%; (9) Pre-polymerized composite-based material (PPBC)/2.5%; (10) PPBC/5.0%; (11) PPBC/10.0%; (12) PPBC/20.0%	N6 (Nylon-6 nanofibers); N6-MWCN (Nylon-6 nanofibers with carbon nanotubes)	(1) 86.4 ± 6.76; (2) 106.0 ± 7.60; (3) 96.9 ± 6.60; (4) 94.3 ± 8.40; (5) 116.4 ± 9.32; (6) 118.5 ± 7.72; (7) 104.7 ± 6.92; (8) 106.4 ± 5.66; (9) 9.7 ± 6.83; (10) 91.0 ± 9.11; (11) 90.1 ± 10.24; (12) 105.8 ± 8.36.
Ranjbar et al. (2019)	(1)composite resin; (2)composite resin + CaO/PLA nanoscaffold (10 wt %); (3)composite resin + CaO/PLA nanoscaffold (20 wt %); (4)composite resin + CaO/PLA nanoscaffold (30 wt %); (5)composite resin + CaO/PLA nanoscaffold (40 wt %); (6)composite resin + CaO/PLA nanoscaffold (50 wt %); (7)composite resin + CaO/PLA nanoscaffold (60 wt %); (8)composite resin + CaO/PLA nanoscaffold (70 wt %); (9)composite resin + CaO/PLA nanoscaffold (80 wt %); (10)composite resin + CaO/PLA nanoscaffold (90 wt %); (11)composite resin + CaO/PLA nanoscaffold (100 wt%).	Glass fiber filler	(1) 134; (2) 124; (3) 125; (4) 126; (5) 131; (6) 134; (7) 137; (8) 136; (9) 131; (10) 134; (11) 133
Velo et al. (2019)	(1) RelyX U200 (2) U200 + 1% PDLLA nanofibers (3) U200 + 1% PDLLA nanofibers/niobium (4)U200 + 1% PDLLA nanofibers/niobium and silica	Organic nanofiber PDLLA, inorganic-organic nanofiber PDLLA/niobium, inorganic-organic nanofiber PDLLA/niobium+silica	(1) 42.3 ± 13.2; (2) 57.5 ± 18.3; (3) 71.0 ± 32.0 and (4) 65.9 ± 6.3
Salek et al. (2018)	(1)Nanohybrid-nanofibrous mats 0%; (2)Nanohybrid-nanofibrous mats 0.5%; (3) Nanohybrid-nanofibrous mats 1.5%; (4) Nanohybrid-nanofibrous mats 3%; (5)Nanohybrid-nanofibrous mats 6%; (6)Microhybrid-nanofibrous mats 0%; (7)Microhybrid-nanofibrous mats 0.5%; (8) Microhybrid-nanofibrous mats 1.5%; (9) Microhybrid-nanofibrous mats 3%; (10) Microhybrid-nanofibrous mats 6%; (11)Microfill-	Nylon 66	C17%: (1) 135; (2) 160; (3) 160; (4) 160; (5) 160; (6) 240; (7) 380; (8) 380; (9) 380; (10) 380; (11) 45; (12) 52; (13) 55; (14) 59; (15) 60 / C20%: (1) 135; (2) 160; (3) 160; (4) 160; (5) 160; (6) 240; (7) 380; (8) 380; (9) 380; (10) 380; (11) 45; (12) 52; (13) 60; (14) 60; (15) 61 / C23%: (1) 135; (2) 160; (3) 160; (4) 160; (5) 160; (6) 240; (7) 380;

(continued on next page)

Table 2 (*continued*)

Author, year	Resin-based material and comparisons	Nanofiber type	Flexural strength values (Mean ±SD)
	nanofibrous mats 0%; (12)Microfill-nanofibrous mats 0.5%; (13)Microfill-nanofibrous mats 1.5%; (14)Microfill-nanofibrous mats 3%; (15)Microfill-nanofibrous mats 6%		(8) 380; (9) 380; (10) 380; (11) 45; (12) 52; (13) 60; (14) 62; (15) 62.
Tokar et al. (2018)	(1)Composite resin matrix; (2) Composite resin matrix + 3% N6; (3) Composite resin matrix + 5% N6; (4) Composite resin matrix + 7% N6; (5) Composite resin matrix + 3% PVDF; (6)Composite resin matrix + 5% PVDF; (7)Composite resin matrix + 7% PVDF; (8)Composite resin matrix + 3% PMMA; (9)Composite resin matrix + 5% PMMA; (10)Composite resin matrix + 7% PMMA	Nylon 6 (N6), Polyvinylidene-difluoride (PVDF) and Polymethyl-metacrylate (PMMA).	(1) 82.12 (16.57); (2) 100.19 (12.32); (3) 112.20 (17.42); (4) 94.60(16.24); (5) 94.12 (9.78); (6) 120.79 (21.97); (7) 120.85 (22.25); (8) 121.69 (19.70); (9) 121.03 (16.43); (10) 105.49 (23.06).
Yancey et al. (2018)	(1) NovaPro Fill, Nanova (nanofiber-reinforced hybrid composite); (2) Filtek Z250, 3 M ESPE; (3) Esthet-X HD, Dentsply	Calcium-phosphate (hydroxyapatite) nanofibers	(1) 135.0 (21.4); (2) 160.9(24.2); (3) 130.5 (12.5)
Tsujimoto et al. (2016)	(1) EverX Posterior; (2) TetricEvoCeram Bulk Fill; (3) SureFil SDR Flow; (4) Z100 Restorative; (5) Tetric EvoCeram; (6) Clearfil AP-X.	Short E-glass fiber	(1) 124.3(5.5); (2) 123.3 (10.4); (3) 127.5(8.2); (4) 138.7(7.6); (5) 134.4(8.4); (6) 158.3(12.3)
Wang et al. (2016)	(1) 60 wt% SiO2 microparticles; (2) 5 wt% SiO2 nanoparticles and 60 wt% microparticles; (3) 5 wt% SiO2 nanofibers and 60 wt% microparticles; (4) 10 wt% SiO2 nanoparticles and 60 wt% microparticles; (5) 10 wt% SiO2 nanofibers and 60 wt% microparticles.	SiO_2 nanofibers	(1) 86; (2) 107; (3) 118; (4) 103; (5) 110
Fonseca et al. (2016)	(1) F22.5/P55 with 22.5 wt% of fiber and 55 wt% of filler particles; (2) F25/P52.5 with 25 wt% of fiber and 52.5 wt % of filler particles; (3) F27.5/P50 with 27.5 wt% of fiber and 50 wt% of filler particles; (4) F30/P47.5 with 30 wt% of fiber and 47.5 wt % of filler particles.	E-glass fibers	(1) 217.24 (20.64); (2) 245.77 (26.80); (3) 246.88 (32.28); (4) 259.91(6.01)
Rameshbabu et al. (2015)	(1) 30/70 resin blend - 0 wt% nanofiber; (2) 30/70 resin blend - 3.4 wt % nanofiber; (3) 30/70 resin blend - 5.4 wt% nanofiber; (4) 30/70 resin blend - 7.9 wt% nanofiber; (5) 50/50 resin blend - 0 wt% nanofiber; (6) 50/50 resin blend - 3.4 wt % nanofiber; (7) 50/50 resin blend - 5.4 wt% nanofiber; (8) 50/50 resin blend - 7.9 wt% nanofiber; (9) 70/30 resin blend - 0% wt nanofiber; (10) 70/30 resin blend - 3.4 wt% nanofiber; (11) 70/30 resin blend - 5.4 wt% nanofiber; (12) 70/30 resin blend - 7.9 wt% nanofiber	Alumina microfibers, Silk microfibers and Ceria nanofibers	(1) 92(6.9); (2) 92.7(6.5); (3) 95.9(2.7); (4) 89.8(9.2); (5) 109.8(3); (6) 104.6(9.6); (7) 106.6(2.1); (8) 104.7(4.2); (9) 119.3(6.9); (10) 114.1 (10.3); (11) 109.1(3.6); (12) 108.6 (6.8)
Cheng et al. (2014)	(1) BisGMA/TEGDMA; (2) PAN; (3) CS-1; (4) CS-2; (5) CS-3; (6) CS-4; (7) PAN + 1.0% NaF; (8) CS-1 + 1.0% NaF; (9) CS-2 + 1.0% NaF; (10) CS-3 + 1.0% NaF; (11) CS-4 + 1.0% NaF	PAN-PMMA core-shell nanofibers	(1) 108.2(9.7); (2) 105.8(7.1); (3) 136.3 (12.9); (4) 124.1(13.1); (5) 116.2(8.3); (6) 125.1(7.7); (7) 105; (8) 136; (9)124.1; (10)116.2; (11)125.1
Garoushi et al. (2013)	(1) EverX Posterior; (2) TetricEvoCeram Bulk Fill; (3) Voco X-tra base; (4) SDR; (5) Venus Bulk Fill; (6) SonicFill; (7) Filtek Bulk Fill; (8) Filtek Superme; (9) Filtek Z250; (10) Alert	Short E-glass fiber filler	(7) 86; (2) 90; (4) 105; (5) 110; (3) 117; (10) 119; (1) 125
Houshyar et al. (2013)	(1) A1: Dental composites + silica 31%; (2) A2: Dental composites + silica 41%; (3) A3: Dental composites + silica 51%; (4) B1: Dental composites + silica 31% + FE 1.02%; (5) B2: Dental composites + silica 41% + FE 0.87%; (6) B3: Dental composites + silica 51% + FE 0.72%	Fuller's Earth (FE) clay	(1) 54.60 (6.39); (2) 73.50(4.44); (3) 81.47 (5.85); (4) 84.60(4.93); (5) 91.34 (6.80); (6) 105.00(5.83)
Moreira et al. (2013)	(1) Organic matrix; (2) Organic matrix + nanoparticulate zirconia; (3) inorganic matrix + nanoparticulate	Ultrafine zirconia fibers	(1) 131.93 (13.8); (2) 130.3(16.8); (3) 136.4 (14.0)

(*continued on next page*)

Table 2 (*continued*)

Author, year	Resin-based material and comparisons	Nanofiber type	Flexural strength values (Mean ±SD)
	zirconia + ultrafine zirconia fibers.		
Garoushi et al. (2012)	(1) Experimental fiber composite resin (FC) + short E-glass fibers (20 mm); (2) FC + short E-glass fibers (15 mm); (3) FC + short E-glass fibers (10 mm); (4) FC + short E-glass fibers (7 mm); (5) FC + short E-glass fibers (6 mm); (6) FC + short E-glass fibers (5 mm); (7) Z250 3 M ESPE (20 mm); (8) Z250 3 M ESPE (15 mm); (9) Z250 3 M ESPE (10 mm); (10) Z250 3 M ESPE (7 mm); (11) Z250 3 M ESPE (6 mm); (12) Z250 3 M ESPE (5 mm)	Short E-glass fibers	(1) 180; (2) 160; (3) 140; (4) 140; (5) 160; (6) 220; (7) 170; (8) 165; (9) 160; (10) 130; (11) 120; (12) 110
Guo et al. (2012)	(1) H-Ctr: Monomer mixture 29%, glass filler 70%, nanofibers 0%, initiator BPO; (2) H1–2.5: Monomer mixture 29%; Glass filler 67.5%; zirconia-silica 1 nanofibers 2.5%; initiator BPO; (3) H1–5.0: Monomer mixture 29%; Glass filler 65%; zirconia-silica 1 nanofibers 5%; initiator BPO; (4) H2–2.5: Monomer mixture 29%; Glass filler 67.5%; zirconia-silica 2 nanofibers 2.5%; initiator BPO; (5) L-Ctr: monomer mixture 29%; glass filler 70%; nanofibers 0%; initiator CQ/4E/PO; (6) L1–2.5: monomer mixture 29%; glass filler 67.5%; zirconia-silica 1 nanofibers 2.5%; initiator CQ/4E/PO; (7) L1–5.0: monomer mixture 29%; glass filler 65%; zirconia-silica 1 nanofibers 5%; initiator CQ/4E/PO; (8) L2–2.5: monomer mixture 29%; glass filler 67.5%; zirconia-silica 2 nanofibers 2.5%; initiator CQ/4E/PO; (9) L2–5.0: monomer mixture 29%; glass filler	Zirconia–silica (ZS) and zirconia–yttria–silica (ZYS) ceramic nanofibers.	(1) 24 h 99.8 (9.4) - 3 month 98.1(12.5) - 6 month 100.7 (6.1); (2) 24 h 128.4(24.4) - 3 month 124.5 (12.9) - 6 months 124.1 (19.1); (3) 24 h 135.4 (16.1); (4) 24 h 135.4 (15.8); (5) 24 h 102.6 (9.4) - 6 month 91.9 ± 13.4; (6) 24 h 143.2 (20.5); (7) 24 h 141.9 (22.3); (8) 24 h 142.7 (17.1) - 6 month 137.4 (18.0); (9) 24 h 142.7 (14.6) - 6 month 115.0 (11.1); (10) 24 h 122.6 (15); (11) 24 h 146.4(10.3)

Author, year	Resin-based material and comparisons	Nanofiber type	Flexural strength values (Mean ±SD)
Sun et al. (2010)	(1) Composite resin; (2) Composite resin-untreated PAN-PMMA nanofiber; (3) Composite resin-treated PAN-PMMA nanofiber 0.6%; (4) Composite resin-treated PAN-PMMA nanofiber 0.8%; (5) Composite resin-treated PAN-PMMA nanofiber 1%; (6) Composite resin-treated PAN-PMMA nanofiber 1.2%; (7) Composite resin-treated PAN-PMMA nanofiber 1.6%	PAN–PMMA core–shell nanofiber	1) 89; (2) 105; (3) 120; (4) 125; (5) 130; (6) 132; (7) 120
Gao et al. (2008)	(1) Dental resin- 0%; (2) Dental resin- 1% aldrich glass powder; (3) Dental resin- 2.5% aldrich glass powder; (4) Dental resin- 5% aldrich glass powder; (5) Dental resin- 7.5% aldrich glass powder; (6) Dental resin- 1% nano-scaled glass fibers; (7) Dental resin- 2.5% nano-scaled glass fibers; (8) Dental resin- 5% nano-scaled glass fibers; (9) Dental resin- 7.5% nano-scaled glass fibers; (10) Dental resin- 1% esstech glass powder; (11) Dental resin- 2.5% esstech glass powder; (12) Dental resin- 5% esstech glass powder; (13) Dental resin- 7.5% esstech glass powder	Nano-scaled glass fiber	(1) 90; (2) 86; (3) 89; (4) 89; (5) 91; (6) 92; (7) 103; (8) 106; (9) 113; (10) 95; (11) 99; (12) 108; (13) 117
Lin et al. (2008)	(1) Bis-GMA resin; (2) Bis-GMA resin + 2.5% PMMA; (3) Bis-GMA resin + 5% PMMA; (4) Bis-GMA resin + 7.5% PMMA; (5) Bis-GMA resin + 10% PMMA; (6) Bis-GMA resin + 2.5% PAN-PMMA; (7) Bis-GMA resin + 5% PAN-PMMA; (8) Bis-GMA resin + 7.5% PAN-PMMA; (9) Bis-GMA resin	PMMA, PAN and PAN-PMMA nanofibers.	(1) 94; (2) 87; (3) 65; (4) 80; (5) 89; (6) 100; (7) 105; (8) 110; (9) 82; (10) 99; (11) 80; (12) 67; (13) 62
Tian et al. (2008)	1) Bis-GMA/TEGDMA dental resins/composites; (2) Bis-GMA/TEGDMA dental resins/composites + 1% nano fibrillar silicate; (3) Bis-	Nylon 6	(1) 90(4); (2) 126(4); (3) 128(6); (4) 133(7)

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Table 2 (*continued*)

Author, year	Resin-based material and comparisons	Nanofiber type	Flexural strength values (Mean ±SD)
	GMA/TEGDMA dental resins/ composites + 2.5% nano fibrillar silicate; (4) Bis-GMA/TEGDMA dental resins/ composites + 7.5% nano fibrillar silicate.		
Garoushi et al. (2007)	(1) Conventional particulate filler dental composite - Z250 3 M ESPE; (2) Experimental fiber composite (FC) + 22.5 wt% of short E-glass fibers + 22.5 wt% of dimethacrylate-PMMA + 55 wt% SiO2	E-glass fibers	Dry: (1) 110; (2) 210 / Water: (1) 80; (2) 180; / Dehydrate: (1) 105; (2) 195
Tian et al. (2007)	(1) Without nanofiber / 1%; (2) Without nanofiber / 2%; (3) Without nanofiber / 4%; (4) Without nanofiber / 8%; (5) Neat nylon 6 nanofibers / 1%; (6) Neat nylon 6 nanofibers / 2%; (7) Neat nylon 6 nanofibers / 4%; (8) Neat nylon 6 nanofibers / 8%; (9) Nanocomposite nanofibers / 1%; (10) Nanocomposite nanofibers / 2%; (11) Nanocomposite nanofibers / 4%; (12) Nanocomposite nanofibers / 8%	Nylon 6	(1) 93; (2) 95; (3) 90; (4) 87; (5) 92; (6) 105; (7) 97; (8) 89; (9) 105; (10) 115; (11) 100; (12) 90
Fong et al. (2004)	(1) Bis-GMA/ TEGDMA resin; (2) Bis-GMA/TEGDMA resin with 2.5% nanofiber; (3) Bis-GMA/TEGDMA resin with 5% nanofiber; (4) Bis-GMA/TEGDMA resin with 7.5% nanofiber	Nylon 6 nanofibers	(1) 79.8(3.1); (2) 94.6(9.5); (3) 108.8 (11.8); (4) (112.1(12.6)

strength and longevity of dental materials.

FT reflects the resistance to crack propagation from an initiation flaw in materials [32]. The fiber impedes the extension of a crack and develops interlocking bridges behind the progressing crack, dissipating energy by fiber pullout and resulting in graceful rather than catastrophic failure. This is due to the random orientation of microfibers in a resin matrix and the formation of a fiber network, which seemed to have enhanced the ability of the material to resist the fracture propagation as well as to reduce the stress intensity at the crack tip from which a crack propagates in an unstable manner. As a consequence, an increase in the flexural properties and FT can be expected [40]. This property is vital in dental composites because a bulk fracture is one of the main reasons for the reduced life spans of restorations. When 2.5% zirconia-silica nanofibers (ZS – 80% zirconia/20% silica) were added to a composite, FT

Table 3
Main conclusions of all included studies.

Author, year	Mechanical properties evaluated	Conclusions
Jafarnia et al. (2021)	FS, E	FS of everX-Posterior was comparable with two other resin composites, showing higher flexural modulus. EverX Posterior as a short fiber-reinforced composite showed improvements and satisfactory performance in mechanical and physical properties, which make it a reliable base material candidate for large posterior restorations.
Behl et al. (2020)	FS, E, CS	Reinforcing dental composites with micro-sized fibres can enhance flexural and compressive properties. Composition containing 5% of 70 ratio of fibres along with 50% strontium filler particles had higher compressive and flexural properties than particulate filler composite.
Djustiana et al. (2020)	FS	There is no statistically significant between the FS of PMMA-silica nanofiber dental composite compare to PMMA nanofiber dental composite
Lassila et al. (2020)	FS, E, FT	EverX Flow exhibited the highest fracture toughness among the commercial short fiber-reinforced composites tested. NovaPro Fill and everX Flow presented the highest flexural strength values.
Saleem et al. (2020)	CS	The compressive strength of all experimental composites was in acceptable range for oral cavity.
Suzaki et al. (2020)	FS, E, FT	TRINIA can be used as a superior restorative material when specifying directions of its fiber mesh layers
Borges et al. (2019)	FS	N6-MWCNT particles with 2.5 or 5% concentrations should be incorporated to produce a composite resin presenting adequate flexural strength associated with reduced film thickness.
Ranjbar et al. (2019)	FS, E, CS	The suitable FS, E and CS of the nanoscaffold nanocomposites with different concentrations in Heliomolar Flow (Ivoclar Vivodent AG, FL-9494) resin composites promise future use of these structures as dental resin composites
Sharma et al. (2019)	E	The E of dental composites containing varying percentage of hydroxyapatite fibers (0–12%) increased by 8.13%. In comparison to the hydroxyapatite fibers, the silica nanoparticles provided significant mechanical reinforcement effect.
Velo et al. (2019)	FS, H	The incorporation of 1 wt% inorganic–organic hybrid fibers embedded with niobium pentoxide provided the highest mechanical properties among all materials tested, which makes them a potential reinforcing agent for resin cements
Lassila et al. (2019)	FS, E, FT	The new short fiber-reinforced flowable resin composite revealed improved FT compared with the flowable bulk fill resin composites. This could suggest better performance of short fiber-reinforced flowable resin composite in high stress-bearing
Salek et al. (2018)	FS, E, H	Incorporation of nylon 66 nanofiber and increasing the fiber diameter and weight fraction of the nanofibers in the matrix, flexural strength, elastic modulus, work of fracture, and hardness of the composite resins were improved

(*continued on next page*)

Table 3 (*continued*)

Author, year	Mechanical properties evaluated	Conclusions
		significantly, indicating the superiority of the reinforced dental composites over the pure composites for tooth color restoration applications
Tokar et al. (2018)	FS, E	Mechanical test results showed that produced nanofibres improved the mechanical properties of dental composite resins. The resulting mechanical properties of this polymer alloy were found to be higher than the neat resin.
Yancey et al. (2018)	FS, E	NovaPro Fill had similar FS, but significantly greater E when compared to Esthet-X HD. When compared to Filtek Z250, NovaPro Fill had significantly lower FS and E. Based on the properties tested, there may not be any significant advantage to the use of the new nanofiber composite restorative material (NovaPro Fill) when compared to the use of traditional hybrid
Tsujimoto et al. (2016)	FS, E, FT	Short fiber-reinforced resin composite showed improvements in fracture toughness compared with conventional glass/ceramic-filled resin composite. The enhanced mechanical properties of the short fiber-reinforced resin composite suggest that might perform better
Bocalon et al. (2016)	E	Replacing 3 vol% of particles by fibers resulted in significantly higher polymerization stress, which was associated to a decrease in E compared to the control.
Wang et al. (2016)	FS, E	The nanofiber containing composite resins produced in this study possess great potential for improving the efficiency and durability of dental restorations.
Fonseca et al. (2016)	FS, DTS	Increasing the fibers content until 30% (wt%) in a BISGMA/TEGDMA particle filled resin increases its diametral and flexural strength.
Rameshbabu et al. (2015)	FS, E, CS	Reinforced composite resins revealed significant improvements in physical and mechanical properties indicating their plausible application as additives in composite dental filler.
Vidotti et al. (2015)	FS, E	The incorporation of PAN nanofibers into different methacrylate resin blends resulted in a desirable toughening effect without compromising other properties, and that this effect is dependent on resin monomer solution composition and nanofiber/resin ratio.
Cheng et al. (2014)	FS,E	NaF-loaded PAN–PMMA core–shell nanofibers were not only able to improve the mechanical properties of restorative resin, but also able to provide sustained fluoride release to help in preventing secondary caries.
Houshyar et al. (2013)	FS, E, FT, H	Different mechanical tests and various parameter measurements demonstrated positive effect of FE nanofibers on mechanical properties of (BisGMA-UDMA-TEGDMA)-silica based composites.
Moreira et al. (2013)	FS, E, H	Zirconia nanofibers showed reinforcement potential considering FS results
Garoushi et al. (2012)	FS, E, FT	The reinforcing effect the composite of that type is higher, when the testing design utilized span lengths close to the length of the fibers instead of span lengths described in testing standards
Garoushi et al. (2013)	FS, E, FT	Short glass fiber reinforced semi-Interpenetrating Polymer Network composite resin (everX Posterior) revealed improvements in physical properties compared with the commercial restorative composites. This could suggest better performance of the new fiber reinforced composite in high stress-bearing
Guo et al. (2012)	FS, E, EAB, FT	Partial substitution (2.5%, 5.0%) of particulate glass filler with zirconia/silica or zirconia/yttria/silica nanofibers can significantly improve mechanical properties (flexural strength and fracture toughness) of the composites.
Chen et al. (2011)	BFS	Impregnation of small mass fractions of the HAP nanofibers into the BisGMA/TEGDMA dental resins (5 wt% or 10 wt%) or into composites (2 wt% or 3 wt%) can substantially improve the biaxial flexural strength, while larger mass fractions could not further increase or even reduce the mechanical properties.
Sun et al. (2010)	FS, E	When 1.2% mass fraction of post-drawn nanofibers were added to Bis-GMA/TEGDMA resin, the FS, E and WOF increased by 51.6%, 64.3% and 152.0%, respectively, compared with neat resin.
Gao et al. (2008)	FS, E	Small mass fraction substitutions (1%, 2.5%, 5%, and 7.5%) of conventional dental filler with the surface silanized electrospun nano-scaled glass fibers significantly improved the FS, E, and WOF values of 70% (mass fraction) filled composites, by as much as 44%, 29%, and 66%, respectively.
Lin et al. (2008)	FS, E	Compared with the neat resin, the FS, E and WOF of the composites reinforced with 7.5 wt% mass fraction of PAN–PMMA nanofibers were increased by 18.7%, 14.1% and 64.8%, respectively.
Tian et al. (2008)	FS, E	The impregnation of small mass fractions of the nano fibrillar silicate into the dental resins/composites could effectively improve the mechanical properties, nano fibrillar silicate may have significant value to be used as the reinforcing nanofiller for dental composites.
Garoushi et al. (2007)	FS, E, FT	Short glass fiber reinforced semi-IPN composite resin revealed improvements in mechanical properties compared with the conventional particulate filler restorative composite.
Tian et al. (2007)	FS, E	Mechanical properties of the dental composites with larger mass fractions (4% and 8%) of nanofibers were less desired.
Fong et al. (2004)	FS, E	Small amounts (e.g. 5.0% mass fraction) of nanofibers can effectively increase the overall mechanical properties of the dental restorative composite resins. Nanofibers might have a bright future to be used as the reinforcing filler in the dental restorative composites.
Krause et al. (1989)	E, CS, FT	Mechanical testing of the resin system showed that the compressive yield strength and elastic modulus increased with increasing filler content, while the tensile strength and strain to failure

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Table 3 (*continued*)

Author, year	Mechanical properties evaluated	Conclusions
		decreased. The fracture toughness increased with increasing filler content up to 50% and 60% and there remained constant.

Abbreviations: Flexural strength (FS); Flexural modulus (E); Fracture toughness (FT); Hardness (H); Compression strength (CS); Biaxial flexural strength (BFS); Energy at break (EAB); Diametral tensile strength (DTS).

increased significantly in relation to control composites without nanofibers; however, a further increase in the fiber content (5.0% or 7.5%) did not lead to a significant change in FT (Table 3). Although the stress-induced phase transformation of zirconia contributes to the toughening effect, the authors also attributed this increase in FT to the incorporation of ZS nanofibers, which play the role of a "bridge" in the fracture regions [32]. Other studies also reported that the FT of resin-based composites is improved when they are reinforced with fibers [25,29,30,40,41,42].

It was also observed that the mechanical properties of resin-based composites are dependent on their compositions and microstructures [26,43]. According to Salek et al. [26], the mechanical properties of FS, E, WOF, and H in different resin composites such as nanohybrid, microhybrid, and microfill were improved by the addition of small weight fractions of nanofibrous mats. Other studies have also shown an improvement in resin-based composites with small mass fractions of nanofibers [7,44-46] and that there is a limit to the amount of nanofiber content by weight before mechanical properties start to decrease [21,32]. On the other hand, some researchers demonstrated that large mass fractions of nanofiber impregnation do not improve the mechanical properties and may even reduce them. Higher mass fractions of powders in the organic matrix enhanced the amounts of voids/defects in the dental composites, or the dental composites may be limited the interfacial bonding strength between the nanofiber filler and dental resin matrix [7].

Most of the studies presented herein evaluated materials containing glass fibers [24,29,30,40,42,43,45,47–52]. There are different compositions of glass fibers, such as S-glass or E-glass, representing different properties, although all of them are amorphous and atoms arranged randomly. Overall, glass fibers-reinforced composites provide high toughness, non-corrosiveness and aesthetic characteristics [24,29,30,40,42,43,45,47–50].

Other factors that may influence the mechanical properties of fiber-reinforced resins are fiber aspect ratios (the ratio between length and width) of nanofibers. Lassila et al. [42] compared five commercial short fiber-reinforced composites (Alert, NovaPro Flow, NovaPro Fill, everX Flow, and everX Posterior), demonstrating that Alert has fiber lengths in the micrometer scale (20–60 µm) and a diameter of 7 µm, while NovaPro composites have fiber diameters in the nanometer scale (50–200 nm) and lengths that range between 100 and 150 µm, which is well below the critical fiber length and desired aspect ratio. This explains the differences in FT values between the commercial short fiber-reinforced composites as can be observed in Table 3. These

Table 4
Quality methodological assessment (Aurélio et al., 2016; Astudillo-Rubio et al., 2018).

Author	Samples obtained through a standardized process	Single operator of the machine	Sample size calculation	Blinding of the testing machine operator	Specimens, test, and formulas according to standard specifications
Behl (2020)	0	1	2	1	0
Bocalon (2016)	0	1	2	1	0
Borges (2019)	0	1	2	1	0
Chen (2011)	0	1	2	1	0
Cheng (2014)	0	1	2	1	0
Djustiana (2020)	0	1	2	1	0
Fong (2004)	0	1	2	1	0
Fonseca (2016)	0	1	2	1	0
Gao (2008)	0	1	2	1	0
Garoushi (2007)	0	1	2	1	0
Garoushi (2012)	0	1	2	1	0
Garoushi (2013)	0	1	2	1	0
Guo (2012)	0	1	2	1	0
Houshyar (2013)	0	1	2	1	0
Jafarnia (2021)	0	1	2	1	0
Krause (1989)	0	1	2	1	0
Lassila (2019)	0	1	2	1	0
Lassila (2020)	0	1	2	1	0
Lin (2008)	0	1	2	1	0
Moreira (2013)	0	1	2	1	0
Rameshbabu (2015)	0	1	2	1	0
Ranjbar (2019)	0	1	2	1	0
Saleem (2020)	0	1	2	1	0
Salek (2018)	0	1	2	1	0
Sharma (2019)	0	1	2	1	0
Sun (2010)	0	1	2	1	0
Suzaki (2020)	0	1	2	1	0
Tian (2007)	0	1	2	1	0
Tian (2008)	0	1	2	1	0
Tokar (2018)	0	1	2	1	0
Tsujimoto (2016)	0	1	2	1	0
Velo (2019)	0	1	2	1	0
Vidotti (2015)	0	1	2	1	0
Wang (2016)	0	1	2	1	0
Yancey (2018)	0	1	2	1	0

0: clearly; 1: partial; 2: not report

Table 5
Assessment of studies using the modified CONSORT checklist (Faggion Jr, 2012).

Author	1	2a	2b	3	4	5	6	7	8	9	10	11	12	13	14
Behl (2020)	No	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Bocalon (2016)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Borges (2019)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Chen (2011)	Yes	Yes	Yes	Yes	P.A.	No	No	No	No	No	Yes	Yes	No	Yes	No
Cheng (2014)	Yes	Yes	Yes	Yes	P.A.	No	No	No	No	No	Yes	No	No	Yes	No
Djustiana (2020)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Fong (2004)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Fonseca (2016)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Gao (2008)	Yes	Yes	Yes	Yes	P.A.	No	No	No	No	No	Yes	Yes	P.A	No	No
Garoushi (2008)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Garoushi (2012)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Garoushi (2013)	Yes	Yes	Yes	Yes	P.A.	No	No	No	No	No	Yes	Yes	No	Yes	No
Guo (2012)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Houshyar (2013)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Jafarnia (2021)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Krause (1989)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Lassila (2019)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	Yes
Lassila (2020)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Lin (2008)	No	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	No	No	No	No
Moreira (2013)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	No
Rameshbabu (2015)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	No
Ranjbar (2019)	No	Yes	Yes	Yes	P.A.	No	No	No	No	No	Yes	No	No	No	No
Saleem (2020)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Salek (2018)	Yes	Yes	Yes	Yes	P.A.	No	No	No	No	No	Yes	Yes	No	No	No
Sharma (2019)	Yes	Yes	Yes	Yes	P.A.	No	No	No	No	No	Yes	No	No	No	No
Sun (2010)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Suzaki (2020)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Tian (2007)	Yes	Yes	Yes	Yes	P.A.	No	No	No	No	No	Yes	No	Yes	Yes	No
Tian (2008)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Tokar (2018)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Tsujimoto (2016)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Velo (2019)	Yes	Yes	Yes	Yes	P.A.	No	No	No	No	No	Yes	Yes	Yes	Yes	No
Vidotti (2015)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Wang (2016)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Yancey (2018)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No

Information regarding the following parameters was judged as reported (Yes), not reported (No) or partially answered (P.A.): (1) Structured summary of trial design, methods, results, and conclusions; (2a) Scientific background and explanation of rationale; (2b) Specific objectives and/or hypotheses; (3) The intervention for each group, including how and when it was administered, with sufficient detail to enable replication; (4) Completely defined, pre-specified primary and secondary measures of outcome, including how and when they were assessed; (5) How sample size was determined; (6) Method used to generate the random allocation sequence; (7) Mechanism used to implement the random allocation sequence (for example, sequentially numbered containers), describing any steps taken to conceal the sequence until intervention was assigned; (8) Who generated the random allocation sequence, who enrolled teeth; (9) If done, who was blinded after assignment to intervention (for example, care providers, those assessing outcomes), and how and who assigned teeth to intervention; (10) Statistical methods used to compare groups for primary and secondary outcomes; (11) For each primary and secondary outcome, results for each group, and the estimated size of the effect and its precision (for example 95% confidence interval); (12) Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses; (13) Sources of funding and other support (for example suppliers of drugs),role of funders; (14) Where the full trial protocol can be accessed, if available.

differences were seen by SEM analysis, which prove that materials with different microstructure characteristics and fiber aspect ratios could differ in their mechanical and physical properties. In the current systematic review, overall, it was showed that experimental composites containing distributed fibers (diameter ranging 100 – 600 nm) are suitable as reinforcement of dental composites.

For anisotropic materials, the properties can also vary according to the orientation of the reinforcing fibers. Fiber-reinforced CAD/CAM resin discs (TRINIA, SHOFU) with woven layers of multi-directional glass fibers such as longitudinal (L), longitudinal-rotated, and anti-longitudinal were compared to a fiber-reinforced composite (everX posterior, GC) and a conventional composite (Beauti core flow paste, SHOFU). The FS of the TRINIA longitudinal group presented values of 254.2 ± 22.3 MPa, which was higher than the standard for the dental resin composites for the core build-up according to ISO4049 (80 MPa). The FT of the TRINIA longitudinal group was 9.1 ± 0.4 MPa, which was significantly higher than that of other composite materials tested. These results suggest that TRINIA can be used as a superior restorative material when specifying the direction of its mesh layers. In the case of a crown, as the basic concept, the longitudinal direction of the TRINIA disc will be located along to the horizontal direction of an occlusal surface of the crown. In addition, TRINIA is possibly available to fabricate post-cores with the longitudinal direction via the CAD/CAM technique [49]. Although fiber-reinforced CAD/CAM resins presented better FS and FT than fiber-reinforced and conventional composites, it should be mentioned that the high pressure and temperature polymerization of these materials under controlled and standardized conditions, allows them a better conversion rate and improved mechanical properties [53].

In 2018, Salek et al. [26] evaluated the microhardness of nano-hybrid, microhybrid, and microfill composites. They observed an improvement of 55%, 32%, and 36%, respectively, when 6% nylon 66 nanofibrous mats were incorporated into the resin matrix [26]. Velo et al. [15] demonstrated higher values of H (55.8 and 60.7 KHN, respectively) of the resin cement (U200) embedded with hybrid nanofibers composed by niobium and PDLLA (Nb_2O_5-filled PDLLA) and with silica (Nb_2O_5/SiO_2) when compared to the control group represented by the commercial self-adhesive resin cement (RelyX U200 – 3 M ESPE), that presented 39.1 KHN [15]. It was also reported higher values of microhardness by a resin matrix modified by nanoparticulate zirconia and ultrafine zirconia fibers (Hybrid – 30.2 ± 0.3 Kgf/mm^2) and a resin matrix incorporated with nanoparticulate zirconia (Nano - 29.9 ± 0.5 Kgf/mm^2) when compared to a resin matrix control (17.0 ± 0.16 Kgf/mm^2) [54].

Mechanical reinforcement can also be evaluated via indirect methods such as shrinkage, stress, depth of cure, or degree of conversion. Although the current systematic review did not include indirect methods to evaluate the mechanical properties of fiber-reinforced resins, the composition of light-cured resins also affected such properties and should be discussed. For instance, the H of a material is often used as an approximate indication of its abrasion resistance or can even correlate with the degree of conversion; however, this relationship is not always straightforward [55]. According to the studies included in this review, no correlation between the degree of conversion and H was found [15,32,54,56]. Overall, the lower conversion values can be attributed to the presence of nanofibers, which modifies the polymerization behavior due to the refractive index difference, which influences the reflection and refraction effects that lead to turbidity or opacity. It was observed that nanofibers that present higher diameters or the increasing content of nanofibers obstruct the passage of light [15,32,57].

The magnitude of the shrinkage and the accompanying stress generated by the polymerization reaction of the resin composites are the main causes *in vivo* problems such as poor marginal adaptation, post-operative pain, and recurrent dental caries [24,29]. In general, short randomly-oriented fiber-reinforced composites reported low or similar polymerization shrinkage or stress compared to particulate filler composites [24,30,31,58,59]. The depth of cure is also an important mechanical property for daily clinical practice. The depth of cure (4.02 ± 0.21 mm) of the short fiber-reinforced resin composite tends to be similar to that of bulk-fill resin composites [30] higher than conventional resin composite [24,31], the translucency of short fiber-reinforced resin composites is relatively higher than those of the other tested resin composites; therefore, this may explain the higher depth of cure compared to conventional resin composites, and the similar debt of cure to that of bulk-fill resin composites [30]. On the other hand, Le Bell et al. [60] demonstrated that fiber-reinforced composites conduct and scatter the light better than conventional resin composites.

Since some fiber-reinforced resins have been introduced into the marketplace, it is also important to discusses their performance as resin composites are usually applied in high-stress-bearing areas, especially in large cavities of vital and non-vital posterior teeth [29]. Overall, commercial fiber-reinforced resins combine a resin matrix, randomly-oriented nanofibers, and inorganic particulate fillers. In the current systematic review, EverX Posterior (GC) [29,30,42,49,50], EverX Flow [41], Alert (SYNCA) [29,41], NovaPro Fill (Nanova) [31,41], and NovaPro Flow [42] were evaluated and improvements in mechanical properties compared with the commercial conventional restorative composites were demonstrated. However, Yancey et al. [31] reported that the FS of NanovaPro Fill (Nanova) was not significantly greater than those of the other two conventional composites tested. In this study [31], the authors demonstrated that despite the significant improvement of restorative composites, these materials still can suffer from two key shortcomings, which are a deficiency in mechanical strength and polymerization shrinkage.

Additionally, high-aspect ratio fiber-reinforced composites seem to be not appropriate for restoring the entire cavity of the teeth. Clinically, a highly polished surface is important to avoid biofilm accumulation and color shift overtime [61]. Since fiber-reinforced composites present poor polishing characteristics, a coating of particle-filled composite has been recommended as the last increment of the restoration [59], to avoid these related issues. However, insufficient data was found regarding surface finish characteristics of fiber-reinforced composites in the literature and, more studies should be conducted to evaluate such characteristic in order to extend the clinical applications of fibers-reinforced resin composites.

It should be highlighted that the main purpose of the current study was to evaluate the effect of nanofibers as reinforcements in resin-based composites using direct methods. Based on the results presented here, it is possible to conclude that both experimental and commercial fibers-reinforced resin-based composites overall demonstrated high mechanical properties [62-66], especially FS and E, making them promising materials for restorations in high-stress-bearing application areas and large cavities in posterior teeth. However, more robust studies are needed to confirm the effectiveness of resin-based dental materials [67] and how they perform in high-stress areas, as well as their biological effect [68].

Nowadays, the focus is to develop a variety of novel biomaterials and composites with enhanced cell viability, cell proliferation, and printability [69]. Various configurations of nanofibers include 3D-scaffolds, fiber mats, foams, and cotton-wool-like nanofibers that can even be 3D-printed [27], achieving remarkable perspectives in regenerative medicine and tissue engineering, as they are able to present various biochemical and/or functional requirements produced by different combinations of biomaterials that can be used for biological purposes [69].

The limitations of this systematic review include a great heterogeneity in the types of nanofibers used and methodologies of the selected studies, which make it difficult to conduct a meta-analysis. In addition, the paucity of methods for assessing the methodological quality for *in vitro* studies make the comparisons of the results difficult. For this reason, we applied guidelines for improving quality and transparency in the included *in vitro* studies, and the most common limitations found were with the sample size calculation, the random allocation sequence, and blinding of the testing machine [36–38]. Therefore, based in the current evidence discussed herein, more high-evidence studies or clinical studies are needed to prove the effectiveness of resin-based dental materials and how they perform in high-stress areas.

5. Conclusions

The incorporation of nanofibers provided a general improvement in the mechanical properties tested, suggesting that nanofibers are a potential material to be used as reinforcement for resin-based materials. However, more high-evidence studies are still necessary to prove the effectiveness of these materials.

Conflict of interest

None.

Acknowledgement

This study was financed by the Coordenação de Aperfeiçoamento de Pessoa de Nível Superior – Brazil (CAPES) – Finance Code 001 as part of the master research of the first author. We also thank FAPESP (18/15145-8) for support with funding for the last author of this study (M.M.A.C. Velo).

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