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Review Article

A potential application of materials based on a polymer and CAD/CAM composite resins in prosthetic dentistry

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Abstract

Purpose: A bioactive high performance polymer (BioHPP) and computer-aided design/computer-aided manufacturing (CAD/CAM) composite resin materials are a relatively new class of dental biomaterials, that are biocompatible and have good aesthetic features. In this review paper, we will summarize literature and publication data on the characteristics of the mentioned materials, as well as their potential application in the dental prosthetics.

Study selection: Available studies and literature reviews from PubMed, SCIndex, Scopus and Google Scholar corresponding to polyetheretherketone (PEEK), high-performance polymers, reinforced composite materials, composite materials, resins, glass-fiber reinforced materials, CAD/CAM materials, dental implants, removable and fixed dental were reviewed.

Results: To avoid many disadvantages of metals and their alloys in dental practice, such as inadequate color, high density, thermal conductivity and possible allergic reactions, materials based on polymers (such as BioHPP), and CAD/CAM composite resins are being developed. These materials have significantly better aesthetics and physical-mechanical properties. They are biocompatible materials that are lightweight, resistant, durable, exhibit high bending and compression resistance.

Conclusions: The use of CAD/CAM composite resin materials and BioHPP in dentistry has begun recently, so the data about their potential clinical use are limited. Most of their features have been demonstrated through laboratory testing, while clinical studies are relatively scarce, so the need for further clinical trials is emphasized.

Keywords: *Polymers, PEEK, BioHPP, Resins, CAD/CAM*

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1. Introduction

Reconstruction of lost and caries-destroyed dental tissues, restoration of the original function and achievement of maximum aesthetic performance are the primary goals in dentistry [1]. It is essential to use materials of excellent mechanical and physical characteristics that will meet these requirements. The gold standard in prosthetics is a combination of precious and base metal alloys and ceramics, owing to their good mechanical and aesthetical properties [2]. Precious metals such as gold are relatively well tolerated in the oral cavity. However, the combination of different metals in the mouth, and the dissolution of metal ions in the saliva can cause galvanic corrosion, thereby compromising their biocompatibility [3,4]. Even for titanium, which is known to be corrosion-resistant, the study of Foti et al. proved that, in the state of polymetalism, titanium can corrode [5]. Study of Fretwurst et al. showed that titanium can be the reason for increased inflammatory response in peri-implant tissue [6]. Due to the disadvantages of metal alloys, such as unmatching colors of the teeth and dental tissues, thermal and electrical conductivity, high weight and density, potential allergenicity and relatively long processing time, there is an increasing number of studies examining materials with certain advantages over the traditional metal-ceramic restorations [7-10]. This primarily refers to materials with outmatching characteristics, biomechanical properties similar to the natural dentition, biomorphism, and a possibility of reparation [1,9]. Such material are glass-ceramics (particularly heat pressed glass-ceramics), crystalline ceramics (alumina), polycrystalline (alumina and zirconia) ceramics and various types of resins and polymers [11,12]. Due to the limited application of pressed ceramics, and frequent cracking of porcelain layers in zirconia ceramics [13], the latest studies have examined a new class of biomaterials, belonging to a large group of resin-based materials and polymers, that are glass-fiber or ceramics reinforced. They are computer-aided design/computer-aided manufacturing (CAD/CAM) composite resin materials, as well as polymer based on polyetheretherketone (PEEK), such as BioHPP (Bioactive High Performance Polymer) [14-18]. A reinforcement of resin materials with glass-fibers or ceramics significantly improves their mechanical and functional-aesthetic characteristics and their biological tolerance [1]. The results of individual studies have shown that resin materials can evenly distribute chewing loads and absorb a part of the applied load [19]. The use of CAD/CAM composite resins and BioHPP in dentistry

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has begun recently, so the data and researches about their characteristics and possible clinical use are ongoing. Although these two groups of materials differ in structure, they have the same way of processing in dentistry by CAD/CAM machine, and some of their indications in prosthetic dentistry intertwine. The aim of this review is to summarize the available literature data on the properties of BioHPP and CAD/CAM composite resin materials, and on their potential application in the prosthetic rehabilitation of patients, with certain demarcations related to their physical-mechanical properties.

1. Materials and methods

In this paper, we reviewed studies from the period of 1999. to 2020. and had to meet the following criteria: clinical cases, clinical reports, experimental studies, and review articles related to Trinia, BioHPP (PEEK), Lava Ultimate, Cerasmart, Block HC, Brilliant Crios, Vita Enamic and other reinforced resin materials for CAD/CAM. The studies with material properties inadequately described, letters to editors, personal opinions and studies of limited accessibility were excluded from this paper. A search of published studies was conducted electronically, through the following databases: MEDLINE (Pubmed), Serbian Citation Index (SCIndex), Scopus and Google Scholar respectively, for the keywords: PEEK, polyetheretherketone, high-performance polymers, reinforced composite material, fiber reinforced composite material, glass fiber reinforced composite material, resins, CAD/CAM materials, dental implant, removable dental, fixed dental (Fig. 1). Table 1 summarizes the data from all experimental and clinical studies with full text access, that are involved in this paper.

2. PEEK and modified PEEK – BioHPP

BioHPP is a part of PEEK family, which is a relatively new material in a group of high-temperature thermoplastic and high-performance polymers. The original PEEK belongs to the polyketone family of aromatic polymers, with a semi-crystalline linear structure [20]. The chemical structure of PEEK $(\text{-}C_6H_4\text{-}OC_6H_4\text{-}O\text{-}C_6H_4\text{-}CO\text{-})_n$ [20] makes it extremely stable at high temperatures with melting point is about 335ºC. That is the reason why this material was interesting and useful in the industry [3,21]. Its tensile strength is about 80 MPa [21], while the density of PEEK is 1300 kg/m^3 [20].

At the end of the 1990s, this material was commercialized in orthopedic surgery and traumatology where it was used to replace metal implant structures [22]. The validity of the application of PEEK for the manufacture of various implants lies in its outstanding physical and chemical properties.

PEEK is a tooth-colored material [21] with high purity and elasticity (Young`s elastic modulus is about 3-4 GPa), similar to those of human bone [23]. It is radiolucent, non-corrosive, non-toxic, non-allergenic, and stable to heat and sterilization. It is resistant to hydrolysis and shows good biocompatibility [23]. Another thing that is also important for its application in implant technology is its low water sorption rate and small solubility. This fact was demonstrated by Lieberman et al. [24]. An *in vitro* study showed that PEEK has the smallest solubility in physiological saliva (0.33±0.11 μg/mm^3) compared with materials based on polymethyl methacrylate (0.99±0.37-1.41±0.24 μg/mm^3) and composite resin (0.84±0.4 μg/mm^3). Same is true for water absorption where the PEEK (6.5 μg/mm^3) [15] absorbed <50% less water than resins (10.6-18.8 μg/mm^3)[24,25]. Also, flexural strength about 170.37±19.31 MPa [26] and high modulus of elasticity of 3-4 GPa [23] may alleviate the possibility of the material from breaking, and give it a consistency similar to the bone [27].

Due to its excellent physical and biological properties, in addition to other medical applications, PEEK is also used in dentistry for making implants, provisional abutments, implant-supported bar, clamp material in the field of removable dental prostheses (RDPs) or fixed prosthodontics [28].

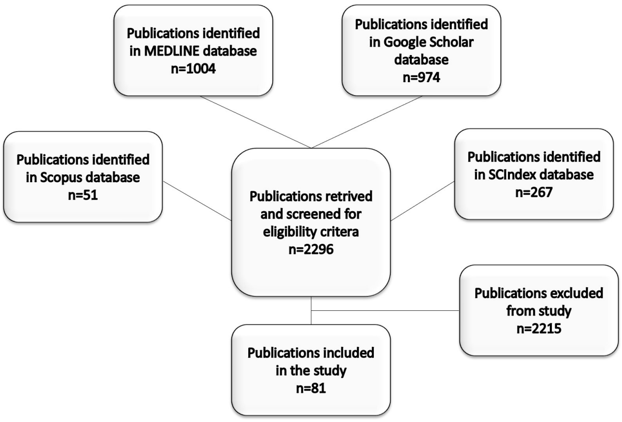

Fig. 1. Selection of studies.

There are two ways of processing PEEK in dentistry. One way of manufacturing is milling from CAD/CAM blocks, and the other is vacuum pressing (pressing from granules or pellets). It should be emphasized that the way of processing can affect the mechanical properties and fracture load of PEEK, and the restoration made from this material [28]. So, the research of Stawarczyk et al. showed that industrial pre-pressing of blocks, such as CAD/CAM or pellet blocks, increased the mechanical properties and reliability of PEEK restorations [29].

Another good feature of PEEK and related to PEEK based materials is a low plaque affinity. This feature was also confirmed by Hahn et al. in their research, stating that the formation of dental biofilm on the PEEK surface is equal or even lower than other prosthetic materials, such as titanium and zirconia ceramics [30].

Although PEEK is fairly resilient to fracture load, there have been studies showing that this material is mechanically relatively weak in a homogeneous form, as shown by Tannous et al. [31]. They proved *in vitro* that clasps made of the cobalt-chromium (Co-Cr) alloy showed significantly higher retention force than PEEK. To improve the mechanical properties and bioactivity of PEEK, scientists have investigated possible combinations with other materials.

By adding 20% of a special ceramic filler to PEEK, a bioactive thermoplastic high-performance polymer-BioHPP is obtained [32]. This polymer has recently been modified by Bredent (BioHPP, Bredent, GmbH, Senden, Germany) solely for use in dentistry. The size of ceramic particles in BioHPP is about 0.3 to 0.5 microns, which results in a consistent homogeneity in the polymer structure and thus optimizes its mechanical properties [32].

The elasticity modulus of BioHPP is similar to PEEK. It is about 4 GPa, which is quite close to the elasticity of the human bone (like in mandible) [15]. Because of this, BioHPP can be useful in implantology, as it can reduce stress in the occurrence of the force of twisting. It can also stimulate bone remodeling around the implant. Having in mind a good biological tolerance of high-performance polymer, Wesley and Özcan described a potential application of BioHPP in the production of implants and abutments, as an alternative to titanium [33]. Its good biological tolerance was also suggested by Koutouzis et al. [34]. In a controlled clinical trial, they showed no increased risk of marginal bone loss and soft tissue recession, when applying polymer healing abutments, compared to titanium, during the initial healing period [34].

BioHPP exhibits the property of poor solubility in water, <0.3 μg/mm^3, and the value of water absorption is about 6.5 μg/mm^3 [15]. The properties of poor solubility in water and poor reactions with other materials can also be used in prosthetic dentistry for restorations in patients who are allergic to Co-Cr alloy or who are sensitive to metallic taste in conventional Co-Cr dentures [32].

Table 1. Overview of included studies, types of studies, used materials and therapeutic modalities.

Publication ID	Study design	Study question (problem)	Number of cases	Material used	Therapeutic modality or method of use	Study conclusion
Passaretti et al. 2018 [1]	Clinical	Prosthetic rehabilitation of edentulous mandible	NR*	Bicon implants and Trinia (FRC)	Fixed prosthesis on short implants	Trinia could be material of choice when there is possibility for fixed denture on implants
Merk et al. 2016 [3]	Experimental	Retention load between ZrO_2 primary crowns and secondary PEEK crowns	90 crowns	Zirconium dioxide and PEEK	Double crowns	In assessing retention load, PEEK may be a suitable material for removable prosthesis and telescopic crown technique when used on zirconia crowns
Keulemans et al. 2009 [8]	Experimental	*In vitro* evaluation of the influence of fiber-reinforcement on the fracture strength and fatigue resistance of resin-based composites	100 rectangular bar-shaped specimens	PFC, FRC, PFC and FRC combined	Rectangular bar-shaped specimens	FRC showed better characteristics,fatigue resistance and fracture strength than PFC and its combination with FRC
Başaran et al. 2013 [9]	Experimental	Comparison of the load bearing capacity of fiber-reinforced and unreinforced CAD/CAM fabricated fixed dental prostheses	38	FRC and Experimental FRC	Fixed dental prosthesis	Experimental fiber-reinforced resin blocks had better load-bearing capacities than unreinforced resin blocks
Cekic-Nagas at al. 2016 [12]	Experimental	Determination of the effect of hydro-fluoric acid on *in vitro* micro-shear bond strength of resin cement system to ceramics	288 specimens	VITA Enamic, LAVA Ultimate, Cerasmart	1,5mm thick speciments	Hydro-fluoric acid does not affect on bond strength, but combination of resin cements and ceramic/glass-polymer materials significantly affect micro-shear bond strength
Erkmen et al. 2011 [14]	Experimental	Comparison of implant retained fixed partial dentures with metal and fiber reinforced composite frameworks	2 models	Metal and FRC	Fixed partial dentures	FRC showed better load distribution and less load-bearing stress on structures and tissue
Bechir et al. 2016 [15]	Clinical	Advantages of BioHPP polymer as superstructure on implants	35 patients, 17 females and 18 males	Modified PEEK - BioHPP	Framework for fixed prosthetic restoration	BioHPP showed good biocompatibility, mechanical characteristics and good adaptation for patients
Bonfante et al. 2015 [16]	Experimental	Evaluating of the probability of survival, strength characteristics and failure modes of CAD/CAM FRC	108 implants	FRC	Implant substructures	There was no difference between 12 mm^2 and 3 mm^2, but difference in failure modes were detected
Biris et al. 2017 [17]	Clinical	Using Trinia for abutments on Bicon implants	24 patients, 15 females and 9 males	Trinia	Implant abutments	Trinia showed good mechanical characteristics and good adaptation for patients
Biris et al. 2018 [18]	Clinical	Usage of BioHPP and Trinia resins as core in fixed prosthetic rehabilitation	33 patients, 17 females and 16 males	BioHPP and Trinia	Fixed dental prosthesis	BioHPP and Trinia both showed expected good clinical characteristics
Yousry et al. 2018 [23]	Experimental	Evaluation of strength of CAD/CAM BioHPP with veneering composite using two different adhesives and two types of cements	40 CAD/CAM blocks	BioHPP (PEEK)	Veneers	Share-bond strength between BioHPP and dentin is better when using Fuji plus (resin reinforced glass ionomer)
Lieberman et al. 2016 [24]	Experimental	Effects of different aging regimens/durations on roughness, solubility, water absorption, Martens hardness (HM), and indentation modulus/EIT on different CAD/CAM polymers	40 specimens	PEEK, LAVA Ultimate and other	Standardized specimens	The hardness parameters of PEEK showed no statistical difference comparing to PMMA-based materials
Misilli et al. 2017 [25]	Experimental	Comparison of the degree of water sorption and solubility in bulk-fills after curing with a polywave light source	120 specimens	Voco, Ivoclar Vivadent, Kerr and 3M ESPE	Disc-shaped specimens	Water sorption and solubility values are affected by the filler ratio and type of resin matrix, regardless of the composite type
Schwitalla et al. 2015 [26]	Experimental	Evaluation of the mechanical properties of different commercial PEEK compounds via three-point-bending tests	150 specimens	PEEK	Bars	In comparison to the prevailing minimum strength for plastic materials their superiority is evidently presented by the characteristic of maintaining their stability despite alternating temperature changes
Siewert et al. 2013 [27]	Clinical	Usage of PEEK as a framework material for removable dental prosthesis	2 patients	PEEK	Framework for a dental bridge	BioHPP showed good mechanical characteristics and biocompatibility

Stock et al. 2016 [28]	Experimental	Assessment of retention forces of secondary PEEK crowns	90 specimens	BioHPP (PEEK)	Secondary telescopic crowns	Milled PEEK crowns had different retention based on taper angle, while pressed PEEK crowns had the same retention force
Stawarczyk et al. 2013 [29]	Experimental	Fracture load evaluation of fixed dental prosthesis made of PEEK	45 specimens	PEEK	Fixed dental prosthesis	PEEK/C reinforced with other inorganic fillers can be potentially used as crown and bridge material
Hahnel et al. 2014 [30]	Experimental	Formation of biofilms on the surface of materials applied for the fabrication of implant abutments	40 specimens	PEEK	Implant abutments	Biofilm formation on the surface of PEEK is equal or lower than on the surface of conventionally applied abutment materials
Tannous et al. 2011 [31]	Experimental	Evaluation of the retentive force of clasps made from three thermoplastic resins and cobalt–chromium (Co-Cr) alloy	112 specimens	PEEK	Clasps	Adequately designed PEEK clasps might be sufficient for clinical use, but had lower retention than Co-Cr alloy
Koutouzis et al. 2011 [34]	Clinical	Evaluation of soft and hard tissue responses to titanium and polymer healing abutments	16 patients	PEEK	Abutments	PEEK healing abutments had lower risk for marginal bone loss and soft tissue recession than titanium
Zoidis et al. 2015 [35]	Clinical	Practical use of removable dental prosthesis frameworks made of PEEK	1 patient	PEEK	Removable dental prosthesis frameworks	BioHPP should not be considered as a substitute framework material for a well-designed Co-Cr RPD, except in patient with taste sensitivity, allergies, additional periodontal support for teeth
Costa-Palau et al. 2014 [36]	Clinical	Practical use of PEEK for making maxillary obturator prosthesis	1 patient	PEEK	Obturator prosthesis	PEEK can be used in maxillofacial reconstructive therapy
Andrikopoulou et al. 2016 [38]	Clinical	Use of PEEK for fixed dental prosthesis	1 patient	PEEK	Fixed dental prosthesis	BioHPP can be used as an alternative treatment option
Lucsanszky et al. 2020 [46]	Experimental	Comparison of the fracture toughness, flexural strength and flexural modulus	5 blocks	CERASMART, KZR-CAD-HR2, CAMouflage NOW, Enamic, Obsidian	CAD/CAM blocks	Resin composite block materials had inferior flexural strength, flexural modulus and fracture toughness than Obsidian and inferior flexural modulus than Enamic
Wang et al. 2017 [50]	Experimental	PICN and CAD/CAM blocks compared to natural teeth	NR	Experimental composites, LAVA Ultimate	Blocks and bars	PICN showed more similar mechanical properties and biocompatibility to natural teeth comparing to common CAD/CAM blocks, except in brittleness index
Takahashi et al. 2005 [52]	Experimental	The effect of water absorption on the impact strengths of FRC bar shaped specimens	32 specimens	FRC	Bar shaped specimens	Impregnated FRC possessed impact strength significantly lower than the preimpregnated E-glass FRC
Ewers et al. 2017 [53]	Clinical	CAD/CAM planning and milling procedures for treatment of extremely severe maxillary and mandibular atrophy	101 patients	Trinia	Fixed dental prosthesis on implants	This method is comparable to metal-ceramic restorations
Seemann et al. 2014 [54]	Clinical	Determination of the effectiveness of fixed, fiber-reinforced resin bridges on ultrashort implants with a sufficient implant survival success rate of at least 90% in highly atrophic jaws	10 patients	Trinia	Fixed dental prosthesis	Resin bridges on ultrashort implants have shown equivalent early implant survival rates relative to other single ultra short implants
Bassi et al. 2016 [55]	Experimental	Comparison of mechanical properties of resin-bonded glass fiber-reinforced (TCFRA) and titanium abutments	16 specimens (8 TCFRA and 8 titanium)	Epoxy resin reinforced with glass fiber	Abutments	TCFRA showed reduced stress on the bone-implant interface
Seemann et al. 2018 [59]	Clinical	Evaluation of midterm outcomes of fixed, full-arch, fiber-reinforced resin bridges on ultrashort implants in terms of marginal bone loss and overall implant survival	17 patients	Trinia	Framework for superstructure on implants	Dental bridges retained by four ultra short implants provide a comparatively cost-effective, safe, and stable alternative for prosthetic restoration of the severely atrophic mandible
Spitznagel et al. 2020 [60]	Clinical	Evaluation of clinical outcome of Vita Enamic, CAD/CAM manufactured single crowns after 3 years	34 patients	VITA Enamic	Crowns (76)	PICN CAD/CAM crowns with reduced thickness showed acceptable survival and success rates over a service time of 36 months

Alamoush et al. 2018 [61]	Experimental	Evaluation of the composition of CAD/CAM blocks and their mechanical properties	168 specimens	Resin composite CAD/CAM blocks	CAD/CAM blocks	CAD/CAM composite materials have comparable hardness and modulus of elasticity to tooth structure
Koizumi et al. 2015 [63]	Experimental	Evaluation of the gloss and surface roughness behaviors of newly developed CAD/CAM composite blocks with different filler contents and characteristics	30 specimens	LAVA Ultimate, Cerasmart, Shofu blok and other	Crowns	Significant difference in the gloss unit was detected between the Shofu Block HC material and the ceramic block after toothbrush abrasion
Awada et al. 2015 [65]	Experimental	Comparison of mechanical properties and evaluation of the margin edge quality of recently introduced polymer-based CAD/CAM materials	150 specimens	LAVA Ultimate, Cerasmart and other	Bars	Tested materials had significantly higher flexural strength and modulus of resilience, along with lower flexural modulus values compared with the common ceramic or hybrid materials
Lawson et al. 2016 [67]	Experimental	Comparison of mechanical properties of several CAD/CAM materials	120 specimens	LAVA Ultimate, Cerasmart and other	Bars	The resin ceramics had lower modulus of elasticity and hardness than glass ceramics but had less wear than enamel and glass ceramics
Jassim et al. 2018 [68]	Experimental	Evaluation and comparison of the fracture strength of monolithic crowns fabricated from five different CAD/CAM materials	40 extracted teeth	Reinforced ceramics and other	Monolithic crowns	Reinforced composite block should be used to fabricate monolithic crowns in the premolar area as it provided high fracture strength with the added advantage of easy intra-oral repair of the restoration when needed
Agarwalla et al. 2019 [69]	Experimental	Assessment of the fracture strength, structural reliability, hardness and translucency of a PMMA resin containing graphene-like material and CAD/CAM materials	30 specimens	PMMA, Vita Enamic, Lava Ultimate, and e.max ceramics	Discs	PMMA based resin has been used to fabricate provisional CAD/CAM; Performance of PMMA was similar to VitaEnamic which is used for permanent single tooth restorations
Lim et al. 2016 [71]	Experimental	Investigation of the Weibull parameters and 5% fracture probability of direct, indirect composites, and CAD/CAM composites	120 specimens	Lava Ultimate and VITA Enamic	Disc shaped specimens	Vita Enamic presented the lowest strength and highest Weibull modulus among the materials
Egilmez et al. 2018 [72]	Experimental	Determination of the flexural strength and Weibull characteristics of different CAD/CAM materials after different *in vitro* aging conditions	315 specimens	Cerasmart, Lava Ultimate and Vita Enamic	Blocks	Flexural strength of CAD/CAM materials was significantly decreased by artificial aging; Cyclic loading or HCl exposure does not affect to the flexural strength and structural reliability of Cerasmart and Lava Ultimate
Venturini et al. 2019 [73]	Experimental	Evaluation of the fatigue failure load, number of cycles until failure, and survival probability of adhesively cemented materials with different microstructures (glass-, hybrid- and resin-ceramic) used to manufacture CAD/CAM monolithic restorations	15 specimens	Feldspathic, leucite, lithium disilicate, zirconia-reinforced lithium silicate, polymer-infiltrated ceramic network and resin nanoceramic	Disc shaped specimens	Resin nanoceramic material presented the best fatigue performance due to greater resilience, which enabled more stress absorption through deformation as the main outcome; while glass- and hybrid ceramic materials showed brittleness and radial cracking as the main outcome
Giertmuehlen et al. 2019 [74]	Experimental	Analysis of the effect of material thickness on the fatigue behavior and failure load of VITA Enamic CAD/CAM crowns	28 crowns	VITA Enamic, Monolithic zirconia	Crowns	PICN with a reduced thickness of 1 mm appeared to be a reliable CAD/CAM material for posterior crowns
Papadopoulos et al. 2020 [75]	Experimental	Investigation of the surface roughness and morphology of four different CAD/CAM materials using four different surface treatments	32 slabs	Shofu Block HC, Lava Ultimate, Brilliant Crios and VITA Enamic	Slabs	Surface treatments resulted in higher surface roughness values compared to the control groups
Tekçe et al. 2019 [76]	Experimental	Investigation of the effect of sandblasting powder particles on microtensile bond strength of dual-cure adhesive cement to CAD/CAM blocks	132 specimens	Cerasmart, VITA Enamic,and LAVA Ultimate	Beams	Sandblasting significantly increases surface roughness values and microtensile bond strength of dual-cure adhesive cement of each CAD/CAM restorative

Rosentritt et al. 2019 [77]	Experimental	Investigation of the influence of material, preparation, and pre-treatment on the aging and fracture force of CAD/CAM resin composite molar crowns	80 crowns	Shofu Block HC, Lava Ultimate, Grandio Blocs and Tetric CAD	Crowns	Fracture forces were not influenced by preparation but by the type of material Clinical success and de-bonding of CAD/CAM resin composite crowns is strongly influenced by the type of material and its pre-treatment
Schepke et al. 2015 [80]	Clinical	Evaluation of new dental restorative bonding material to either zirconia stock or customized abutments	50 patients	LAVA Ultimate and others	Crowns	RNC crowns luted to stock and customized zirconia implant abutments with the particular resin composite cement in this trial have a poor prognosis, regardless of the abutment type used
Tsitrou et al. 2007 [81]	Expermental	Investigation of possible correlation between the brittleness index (BI) of machinable dental materials and the chipping factor (CF) of the final restorations	10 specimens	Paradigm MZ100TM, Vita Mark II, ProCAD, IPS e.max CAD	Crowns	BI and marginal chipping are positively corelated, indicating that the BI of a material can be used as a predictor of the CF

* – Not Reported

This high-performance polymer can be used in fixed prosthetics for making crowns and bridges, especially for people suffering from parafunctional activities, such as bruxism. The polymer disables the abrasion of the antagonist teeth and withstands a load of chewing forces without any fractures [32]. In this context, fracture resistance obtained by *in vitro* tests is about 1200 N, which, in comparison to the maximal chewing strength of 500 N, represents an adequate safety limit. The flexural strength of this material is >150 MPa [15].

Owing to its natural tooth color and high strength, BioHPP can be used as an alternative material for removable partial dentures (RPDs) frames, for making metal-free clasps and occlusal rests [32]. The bond strength of BioHPP framework is over 25 MPa [15]. In the development of classical RPD, due to the high elasticity of the alveolar ridges, under the occlusal load, the distally extended part of the prosthesis shows a higher degree of rotation around the support point, which can create a distal torque on the abutment teeth. Zoidis et al. applied a BioHPP frame RPD for the prosthetic rehabilitation of a patient with Kennedy I class in the lower jaw [35]. They used this material with an initial hypothesis that, due to its elasticity, it is possible to reduce the distal moment and the stress around the retention teeth. That showed a BioHPP's potential alternative use in the management of cases with distal extension, and teeth requiring additional periodontal support, taste sensitivity, and Co-Cr allergies. Due to its low specific weight, a BioHPP denture is 27.5% lighter than RPDs with Co-Cr alloy frameworks [35]. This gives a patient satisfaction and comfort while wearing the prosthesis.

Due to biocompatibility and low density of BioHPP, which is about 1.31 g/cm^3, this material is useful for a denture obturator [36]. An *in vitro* test study reports that good polishing of BioHPP with low surface roughness can be achieved either using dental instruments or instruments from dental technicians for the polishing process [37]. These tests show good resistance to abrasion and color stability. As these tests have only confirmed laboratory results, additional clinical research is needed to confirm the BioHPP properties. On the other hand, there is case research conducted by Andrikopoulou et al. reporting the use of the modified PEEK – BioHPP for the fabrication of resin-bonded fixed dental prosthesis framework in young cleft lip and palate patient [38]. It was concluded that BioHPP can`t substitute the conventional metal-ceramic or all-ceramic materials, however, it can be an alternative treatment option, but further long-term clinical evidence is still needed [38].

3. CAD/CAM composite resin materials

One of the first studies examining the properties and application of glass-reinforced composite materials in medicine emerged back in the 1960s [39]. Further studies related to the characteristics and new applications of these materials began in the 1990s, following their increased application in dentistry [40].

On the other hand, the resin-based composites have been used in restorative dentistry for many years. A conventional resin system in dental composites includes dimethacrylates based on bisphenol A glycidyl methacrylate (BisGMA), urethane dimethacrylate (UDMA), and triethylene glycol dimethacrylate (TEGDMA) [41]. Among these systems, the maximal flexural strength of a homopolymer was found at UDMA, being 133.8 MPa [42].

Due to insufficient mechanical characteristics, traditional resin composites are used mainly on anterior teeth or in smaller posterior restoration [43]. In cases of large posterior restorations, in cuspal replacements and patients with parafunctions, it is necessary to improve the mechanical properties of materials and reduce the polymerization shrinkage [44]. One way to improve their performance is through the industrial processing of resin composites using CAD/CAM technology.

Feldspathic ceramics had been used in CAD/CAM restoration, but its use was reduced as new materials with better mechanical properties, such as leucite-reinforced porcelain and lithium-reinforced porcelain, developed [45]. Even though ceramic blocks provide superior mechanical properties, their disadvantages are a need for the firing process, hydrofluoric acid bonding, abrasiveness different from teeth, and brittleness [12,45].

Aiming for the development of material with better characteristics than ceramics and glass ceramics, the production of resin CAD/CAM composite blocks had started. Owing to its composition and structure, CAD/CAM composite resin materials have good esthetical and mechanical properties, such as firmness, flexibility, and durability [1,17]. Compared to metal alloys, it has biocompatibility, while its edge stability, excellent machinability, and reduced brittleness are its advantages, compared to ceramic/glass-ceramic blocks [46].

3.1. CAD/CAM glass-fiber reinforced composite - Trinia

Trinia (Shofu Dental Corporation, San Marcos, USA), a recently introduced indirect resin-based composite material, belongs to a group of glass-reinforced composite materials and is described as a 3D fiber reinforced composite (FRC), manufactured for CAD/CAM applications [17, 47]. It is 60% glass fibers and 40% epoxy resin fabricated through several layers of multi-directional interlacing. Glass-fibers permeate resin layers and give the material the firmness similar to a thermally hardened thermoplastic plate [17,18,48].

Trinia has a high flexural strength of 393 MPa and compressive strength of 374 MPa (parallel force) and 339 MPa (transverse force)

[17]. Another feature is its elasticity modulus, very similar to the dentin elasticity modulus, like other hybrid materials [49]. The elasticity modulus of dentin is 8,7-25 GPa, while Trinia is 18.8 GPa [17,49,50]. Fracture toughness and density of Trinia are 9.7 MPa $m^{1/2}$ and 1.68 g/cm^3, respectively [51].

Aside from adequate strength and resistance to fractures, Trinia possesses a very low water absorption quality, which is about 0.03 % [51,52] and resilience that affects the mucous-bone fundament, comparable to Sharpey's fibers [53]. Trinia can be used to produce a large number of dental restorations such as inlays, onlays, crowns, bridges, veneers, as well as superstructures and supporting structures of dental restorations on implants [16,48,53].

In the pilot study conducted by Seemana et al., Trinia was used as a framework material for the reconstruction of the lower dental arch, with 4 ultra-short implants implanted [54]. Using a metal-free, implant-supported, fixed prosthesis avoids extensive, laborious crafting of heavy metal parts in the restoration suprastructure. Using Trinia, CAD/CAM–milled bridges can withstand chewing forces with no fracture or chipping [54]. However, it is found that opposing dentures in 7 out of 10 patients, limit the bite force. It is necessary to conduct a study with the same problem but with more patients to confirm this conclusion. In a study conducted by Bassi et al., the effect of a force at a certain angle is compared to titanium made abutments and glass-fiber reinforced resins [55]. Glass-fiber reinforced resin abutments show a lower percentage of decementation (37.5 %), and no fracture or deformation of the material, while the decementation and fracture of titanium was 62.5 % and 12.5 % of cases respectively [55].

Biris et al. examined Trinia on the non-metal superstructure and Bicon implants [18]. Eighteen months after the embedding, cementing, and monitoring, it was found out that there were no signs of weakness in the material or fractures on Trinia superstructure or implants. Glass-fiber reinforced resin-based materials have an advantage compared to ceramics when it comes to restorations on implants, due to the lesser impact of the chewing force on the implants up to 50 % [18,56,57].

A study by Passaretti et al. showed that the use of non-metal fixed restorations on implants avoids fracture of the restoration and implants due to the effect of chewing force distribution [1]. The authors also showed that due to the material properties, it was easier to accomplish high-quality polishing, which reduces mucosal irritation and biofilm adhesion [18,51,58].

Seemana et al., in their clinical study used Trinia to make superstructure on Bicon implants to treat the patient with atrophic mandible and concluded that fixed full-arch bridges, made from glass-fiber reinforced resins, retained by four ultrashort implants provide a comparatively cost-effective, safe, and stable alternative for prosthetic restoration of the severely atrophic mandible [59].

One of the disadvantages of Trinia listed in the literature, as well as all materials reinforced with glass particles, is the possibility of mucous membrane irritation if in direct contact. Careful work is advisable while polishing the restorations made from this material [17].

3.2. Other reinforced CAD/CAM composite resins

Unlike Trinia, which contains fiber-glass, the second class of relatively new CAD/CAM materials are resin-matrix ceramics CAD/CAM materials. They combine superior aesthetic properties of ceramics and positive properties of nonbrittle composites and polymer. These materials can be divided according to microstructure and manufacturing process into two groups: ceramic particle-filled composites with dispersed fillers and polymer-infiltrated ceramic networks (PICNs) [60] (Table 2). The first group is the composites consisting of basic monomer type as organic matrix and dispersed fillers (zirconia, silica, barium glass). They are Lava Ultimate (LU) (3M ESPE, StPaul, MN, USA), Cerasmart (GC America, Alsip, IL, USA), Block HC (BHC) (Shofu Block HC, Shofu Inc., Kyoto, Japan) and Brilliant Crios (BC) (Colten, Switzerland) [61, 62-65]. The other group is PICN materials consists of porous ceramic scaffold structure which is infiltrated with monomer mixture, making the material less brittle than ceramics. VITA Enamic (VE) (Vita Zahnfabrik H. Rauter, Bad Säckingen, Germany) is one of the recently developed PICN material, called hybrid ceramic, and consists of feldspathic ceramic network 86% by weight, that is fully integrated with polymer network (14% by weight) [66].

The LU material consists of 80% ceramic particles, and 20% composite resin, so it is called nano-ceramic resin [64]. Cerasmart is a nanoparticle-filled high-density composite resin, which contains 71% of filler particles by weight [65]. BHC from Shofu is composed of 61% by weight of silica powder, zirconium silicate, and micro-clustered silica particles in a resin matrix and it is available as blocks or discs for CAD/CAM milling [62]. BC is also a resin block that is reinforced with 70% of glass and amorphous silica [61].

Compared to Trinia, whose Young`s modulus is closest to dentin, the specified CAD/CAM ceramic reinforced composite materials have slightly lower values of elastic modulus (Table 3) [17,49,50,67,68]. The elastic modulus of the material, which is near as in dentin, enables better load distribution on dentin rather than accumulating in restorations [68].

Flexural strength of LU and Cerasmart is examined in the study of Lawson et al. and is compared with glass-ceramic material (e.max CAD and Celtra Duo) showing a value of 248.4 MPa for LU and 234.5 MPa for Cerasmart [67]. Their results differ from a study in which flexural strength for LU (178 MPa) was significantly lower than for Cerasmart (219 MPa) [65]. The value of flexural strength for LU, which is closer to the study of Lawson et al., was obtained in a study of Agarwalla et al., and its value was 201 MPa [69]. Flexural strength for BC and BHC is 198 MPa and 170 MPa, respectively [47,65]. The flexural strength of CAD/CAM composite resin materials is higher than that of conventional composite resin [70], probably because of the high filler load in CAD/CAM materials and factory polymerization, which involve heat and pressure [49]. Flexural strength values of CAD/CAM ceramic reinforced composites are lower than Trinia but are closer to BioHPP (>150 MPa) [17,20,47,65,67,68]. Lim et al. showed that VE had a flexural strength of about 108.7 MPa, lower than LU and direct composite material that was examined. They consider that porous feldspathic ceramic matrix, infiltrated in monomer in VE is responsible for the increased ability of the material to withstand mechanical stress by deforming elastically rather than fracturing. Also, they consider that the microstructure of LU, as well as, wider distribution of silica/zirconia particles increases the likelihood for crack deflection and increases flexural strength of this material [71].

However, Lucsanszky and Ruse tested flexural strength, flexural modulus, and fracture toughness of VE and Cerasmart related to lithium disilicate glass-ceramic blocks (Obsidian) and showed that VE and Cerasmart have lower values of examined parameters [46]. Also, they determined that flexural modulus for VE (33.02 GPa) is higher than Cerasmart (9.25 GPa), as well as, aging of materials have a significant impact on flexural strength leading to lowering this values, while it does not affect the flexural modulus.

Jassim and Majeed examined the values of flexural and fracture strength for monolithic crowns fabricated from BC, glass-ceramic materials (lithium disilicate and zirconia-reinforced lithium silicate) and hybrid ceramic (VE) [68]. They showed that the flexural strength of BC (198 MPa) and VE (150-160 MPa) is much lower than that of ceramic materials (360 MPa and 370 MPa), while the fracture strength is significantly higher for BC (1880 N) than ceramic materials (1085 N and 1404 N). VE had the lowest value for fracture strength (767 N). Thus, they concluded that the chemical composition and microstructure of the material had a significant impact on the fracture strength of the fabricated crowns. Nevertheless, in brittle materials, such as ceramics, the value of flexural strength should not be taken alone to indicate structural performance because material strength is conditional [68]. Since the fracture strength of all crowns exceeds the maximum biting

Table 2. Composition and indication of examined polymers and CAD/CAM composite resin materials.

Material	Filler particule (%)	Resin monomer	Manufacturer	Indication (by manufacturer)
PEEK	/	Aromatic polymer (poly-ether-ether ketone)	/	Dental implants, implant abutments, framework for RPDs, fixed crowns and bridges
BioHPP	20% ceramic filler	Polymer (poly-ether-ether-ketone)	Bredent	Abutment, telescopic crowns, framework for RPDs
Trinia	60% glass-fiber	40% epoxy resin	SHOFU	Substructures or frameworks for permanent and transitional anterior or posterior crowns, bridgework, telescopic restorations
Lava Ultimate	80% SiO_2 (20 nm), ZrO_2 (4–11 nm), aggregated ZrO_2/SiO_2 cluster	Bis-GMA, UDMA, Bis-EMA*, TEGDMA	3M ESPE	Inlays, onlays, veneers
Cerasmart	71 % silica (20 nm), barium glass (300 nm)	Bis-MEPP**, UDMA, DMA***	GC Corporation	Inlays, onlays, crowns, veneers, implant- supported crowns
Block HC	61% silica powder, zirconium silicate, micro-clustered silica	UDMA, TEGDMA	SHOFU	Inlays, onlays, veneers, full crowns for anterior and posterior teeth, implant- supported restorations
Briliant Crios	70% glass and amorphous silica	Cross-linked methacrylates (Bis-GMA, Bis-EMA, TEGDMA)	COLTENE	Inlays, onlays, crowns, veneers, implant-supported restorations
VITA Enamic	86% feldspathic ceramic enriched with aluminium oxide	UDMA, TEGDMA	Vita Zahnfabric	Inlays, onlays, veneers, anterior and posterior crowns, anterior and posterior crowns on implants

*Bis-EMA - ethoxylated bisphenol-A dimethacrylate
**Bis-MEPP - 2,2-Bis(4-methacryloxypolyethoxyphenyl) propane
***DMA - dimethacrylate

Table 3. Elastic (Young`s) modulus of CAD/CAM composite resins.

Material	Modulus of elasticity (GPa)	References
Dentin	8.7-25	[50]
Trinia	18.8	[17]
Lava Ultimate	12.77±0.99	[50]
Cerasmart	9.25-12.1	[46,66]
Block HC	7.2-9.6	[50]
Briliant Crios	10.3	[68]
VITA Enamic	21.2-30.03	[46,67]

force in the premolar region, they suggest that all tested materials could be successfully used clinically as monolithic crown restorations in the premolar region. A similar result of flexural strength for VE (150 MPa) was shown in the study of Agarwalla et al. [69]. In this study, it is also tested Weibull modulus (m) which is a material-specific parameter describing the scatter of strength as a result of flaws within the microstructure. The values that were obtained are 14.3 for VE and 13.5 for LU. In the study of Eglimez et al. that examined Weibull modulus after different *in vitro* aging conditions, values for VE and LU were similar and amounted between 9 to 19.09 according to aging conditions. For Cerasmart Weibull modulus was significantly lower and was in range 7-8 [72].

Venturini et al. *in vitro* evaluated fatigue performance of adhesively cemented glass-, hybrid- (VE) and resin-ceramic (LU) materials for CAD/CAM monolithic restorations [73]. They showed that the microstructure of examined materials affects their performance under fatigue. Resin-ceramic material presented the best fatigue performance due to the greater resilience (survived until the last loading step (2200 N) and the number of cycles (100.000) without radial cracking, which enabled more stress absorption through deformation as the main outcome. Glass- and hybrid-ceramic materials showed brittleness and radial cracking as the main outcome (all PICN specimens failed in the first step (400 N; 10,000)) [73].

On the other hand, Giertmuehlen et al. analyzed the effect of the material thickness (1.5 mm and 1.0 mm) on fatigue behavior (1.2 million cycles, 198 N) and failure load of monolithic PICN (VE) CAD/CAM molar crowns [74]. All PICN specimens survived fatigue exposure, and the conclusion is that PICN with thickness of 1.0 mm appeared to be a reliable CAD/CAM material for posterior crowns.

Similar results were obtained in a controlled *in vivo* clinical trial conducted by Spitznagel et al. [60]. They evaluated the clinical outcomes of monolithic CAD/CAM PICN single crowns with a reduced thickness on premolar and molar teeth, after a 36-month observation period. This study concluded that PICN monolithic crowns showed acceptable survival and success rate after the observed time, but suggested extended clinical follow-up periods for long-term evaluation of material performance [60].

Papadopoulos et al. investigated the surface roughness and morphology of BHC, LU, BC, and VE using four different surface treatments [75]. The surface of the specimens of each material received sandblasting with 29 µm Al_2O_3 particles, 9% hydrofluoric acid etching and silane application, and the tribochemical method using CoJet System. Also, they had control specimens of each material with no surface treatment. Compared to the control groups, surface treatments in all tested materials resulted in higher surface roughness values, but there were not negligible differences among the surface treatments. The influence of treatments to surface properties of the tested materials is probably due to discrepancies in their composition and structure [75]. Tekce et al. got similar results while investigated the effect of sandblasting power particles on microtensile bond strength of dual-cure adhesive cement (G-CEM LinkForce) to CAD/CAM materials (LU, VE, Cerasmart). They concluded that sandblasting significantly increased surface roughness values of investigated CAD/CAM materials [76].

The fields of application of CAD/CAM ceramic reinforced composites (LU, Cerasmart, BC, BHC) are generally similar, so they are used for inlays, onlays, crowns, and veneers [62]. Their application is more focused on minimally invasive dentistry, so in comparison to Trinia, it is limited in the field of implant superstructures, mainly as implant-supported single crown restoration. Due to a high de-bonding rate of LU, crown indication for this material is removed by the manufacturer (3M ESPE) in 2015. Since then, the indication for LU is restricted on inlays, onlays, and veneers [77].

The indications for PICN (VE) are similar to other CAD/CAM composite resin materials: minimally invasive restorations and posterior crowns, veneers, inlays, and onlays for posterior teeth and implant-supported crowns [78]. From this aspect of an application in prosthetics, Trinia is rather comparable to PEEK based materials. (Fig. 2). The main disadvantage associated with the use of these materials is that, to date, a sufficient number of clinical studies have been conducted to define the advantages and disadvantages of materials in clinical practice. This fact that the clinical short and long-term evidence is still scarce is highlighted in the paper of Spitznagel et al. [79]. The study conducted by Schepke et al. analyzed the bonding and performance of single implant restoration made of nanoceramic resin composite material (LU) to either zirconia stock abutments or zirconia customized implant abutments [80]. They concluded that the bond covered crowns and customized zirconia implant abutments with the particular resin composite cement have a poor prognosis, regardless of the abutment type used [80].

What distinguishes these materials from classic ceramics is a lower brittleness index and the chipping factor which is a direct indicator of the marginal degree of chipping. In the study of Tsitrou et al., CAD/CAM composite resins and ceramics were compared for the brittleness index and chipping factor. It was shown that a higher brittleness index is associated with a higher chipping factor. Due to a less brittle structure, ceramic-reinforced composite resins are less sensitive to chipping when processed in thin dimensions [81].

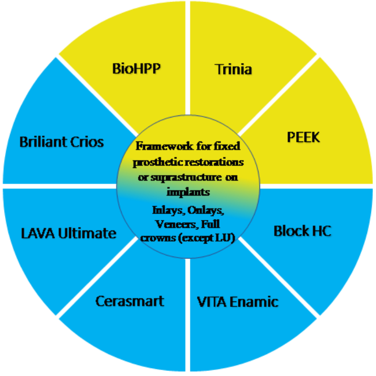

Fig. 2. The most common indications of PEEK, BioHPP, Trinia (yellow - framework for fixed prosthetic restorations or superstructure on implants) and CAD/CAM composite resin materials (blue - inlays, onlays, veneers, full crowns) in prosthetics.

5. Conclusion

BioHPP and CAD/CAM composite resin materials reinforced with glass-fibers and ceramics are innovative biomaterials attracting interest for use in prosthetic dentistry. Based on the available literature data, we concluded that these materials offer many advantages over traditional metal-ceramic materials, such as better aesthetics properties, biocompatibility, and less brittleness. Also, the conclusion is that CAD/CAM composite resin materials have lower mechanical properties related to lithium disilicate glass ceramics, but superior to feldspathic ceramics. Summing up the available literature and publications we concluded that the best indication for using BioHPP and Trinia in prosthetics is making a framework for superstructure on implants. Other CAD/CAM composite resin materials are useful for inlays, onlays, veneers, and full crowns, except for LU that is not suitable for full crowns. Further clinical studies are necessary to confirm the properties and a wider field of application of these materials.

Conflict of interest

There are no potential conflict of interest.

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