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Review

Applications and Clinical Behavior of BioHPP in Prosthetic Dentistry: A Short Review

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Abstract: (1) Background: BioHPP® (Bredent, UK) is a partially crystalline poly ether ether ketone (PEEK) that is strengthened using ceramic. PEEK and its various formulations represent a very interesting alternative, and has been in-depth with its literature in recent years; (2) Methods: A PubMed and Scopus search for the term "BioHPP" yielded 73 results and 42 articles which were included in this short review. Considering the scarce literature on the subject, each article was considered in this review; (3) Results: the articles analyzed are very recent, all published in the last 5 years. Their clinical evaluation of BioHPP® highlights many positive aspects, and few articles have highlighted critical issues in its multiple clinical applications; (4) Conclusions: this material is not only extremely interesting for the future, but possesses characteristics suitable for clinical application today, for endocrowns, small adhesive bridges, temporary prostheses and for immediate loads on implant restorations. The excellent aesthetics and the possibility of simple reprocessing of the restorations made with this material invite its clinical application.

Keywords: BioHPP; crystalline poly ether ether ketone; PEEK; ceramic fillers; dental prostheses; elasticity; rigidity; immediate loading

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1. Introduction

Innovations in the field of implant prosthetics on materials that can be used both in temporary rehabilitation, such as in immediate loading and definitive restorations, have merged with modern digital techniques, making the use of resins and non-metallic materials increasingly interesting. Although metal prosthetic restorations still represent an extremely recommended solution today for the marginal precision, duration over time, excellent bond of the current alloys with the ceramic coatings, and for the possibility of laser sintering, milling the structure, or to use a casting technique, PEEK and its various formulations represent a very interesting alternative, thoroughly investigated in recent literature.

The purpose of this review is to understand the level of awareness of the mechanical characteristics of BioHPP and its ideal clinical application.

Metals prosthetic rehabilitation have a very different modulus of elasticity from those of bone; these rigid materials discharge important occlusal forces on the prosthetic system, without any cushioning, and therefore, for the application in immediate loading techniques, the need arises to use different materials, equipped with the ability to reduce the load on implants [1]. Since the modulus of elasticity for PEEK at around 12 GPa is similar to that of cortical bone at around 15 GPa, it is particularly suitable for dental implants.

Since the matherial is extremely inert and develops a dense structure as a result of the processing during the compression-molding process, there is good biocompatibility, as has already been proven during the manufacture of plastic abutments [1,2].

Polyetheretherketone (PEEK) has been used in medicine for years, particularly in Orthopedics for more than 40 years [2]. This product, and its novel high-performance evolutions, attracted the attention of researchers for the notable mechanical properties. Over the years, this material has evolved, leading to its reinforcement by inserting fibers or ceramics inside (less than 0.5 μm in diameter) to improve its mechanical capabilities, resistance to stress, and aesthetics [3].

BioHPP® (Bredent, UK) is a partially crystalline poly ether ether ketone (PEEK) that is strengthened using ceramic. The ceramic fillers improve the strength, abrasion properties, and allow it to be veneered. As a result, BioHPP® is the only material to achieve the perfect balance between elasticity and rigidity, with important aesthetic characteristics on its side, thanks to the possibility of being veneered [4].

A BioHPP® prosthesis considerably reduces the maximum values of masticatory forces, both vertically and lateral, compared to titanium, zirconium, or ceramic distributed on the prosthetic structure and in the bone [4,5]. One of the functions of Sharpey fibers is to cushion the distribution of occlusal forces at the bone level. This capacity is often lower on devitalized teeth and completely missing in the case of bone ankylosis/osseointegration at the implant level. From a mechanical point of view, this has unfavorable effects on osseointegration, and from a physiological point of view there are effects on the antagonistic teeth as wear. The interposition of a material such as BioHPP®, often used as an abutment between the bone/implant interface and the prosthesis, guarantees greater safety in immediate loading techniques, thanks to its mechanical characteristics [1,5].

The use of this material is indicated in fixed prostheses for single crowns, bridges with up to two pontics, bonded bridges (Maryland bridges), and in removable prostheses for superstructures with or without friction elements, secondary parts in the presence of bars, individual abutments, Toronto Bridge, or, directly, crowns [6]. Particularly with fixed prostheses in a jaw already restored with metal restorations, the low BioHPP® modulus of elasticity can therefore help achieve normal chewing sensation and reduce the amount of force transmitted with implant-based restorations in the manner of "progressive bone loading", reducing also the risk of antagonist chipping due to excessive occlusal load during occlusion [4,5]. The possibility that this material has to adapt perfectly to the partially or completely digital workflow and radiation-free diagnostic examination allows for obtaining high levels of aesthetics, and for being able to propose a precise treatment plan for the patient [7–11]. The main solution for its clinical application to date is still represented by cementation, unless intermediate metal components are used that allow it to be screwed, avoiding the various problems of cementation, which, however, can follow traditional techniques without particular differences using adhesive cements, composites, zinc oxide without eugenol, and zinc oxide with eugenol, avoiding only glass ionomer and zinc phosphates cements [12,13].

What makes this material extremely interesting is that it achieves a perfect balance between elasticity (about 4.200–4.800 MPa) and stiffness (flexural strength 180–185 MPa), weight and breaking strength (from 700 N to 1600 N), physiologic integration, and resistance to plaque (bacterial adhesion comparable to that of zirconium oxide or veneering composites, with perfectly polished surface, polishing up to <0.02 μm) [4,6].

Considering the characteristics of this material, it adapts perfectly to the prosthesis on implants, but less so to the one on the tooth. It must be considered that the dental implants alone represent the answer to the medical needs of more than 800,000 individuals in the United States (US), and more than 1.8 million in the European Union (EU). Often, the placement of a limited number of strategic implants makes it possible to propose low-cost implant therapies, which are suitable for a large part of the population, and these materials, resistant, economical, and suitable for immediate loading represent the future of this kind of rehabilitation [5,6].

Several studies have been proposed on the mechanical properties of this interesting material in vitro (less in vivo), but there are still no reviews of these articles that can offer an overview of this product and its possible applications.

2. Materials and Methods

A PubMed search for the term "BioHPP" yielded 29 results. All the articles were selected, evaluated by their titles and subsequently by their abstracts, and were considered valid for the purposes of the comparative and absolute evaluation of the BioHPP compared to other prosthetic materials; only one article not written in English was excluded. 28 articles were included in this review. Considering the scarcity of literature on the subject, each article was considered in this review.

3. Results

The articles taken into consideration indicated that this examination is widely usable and in great progress. The complete search flow is schematized in Figure 1.

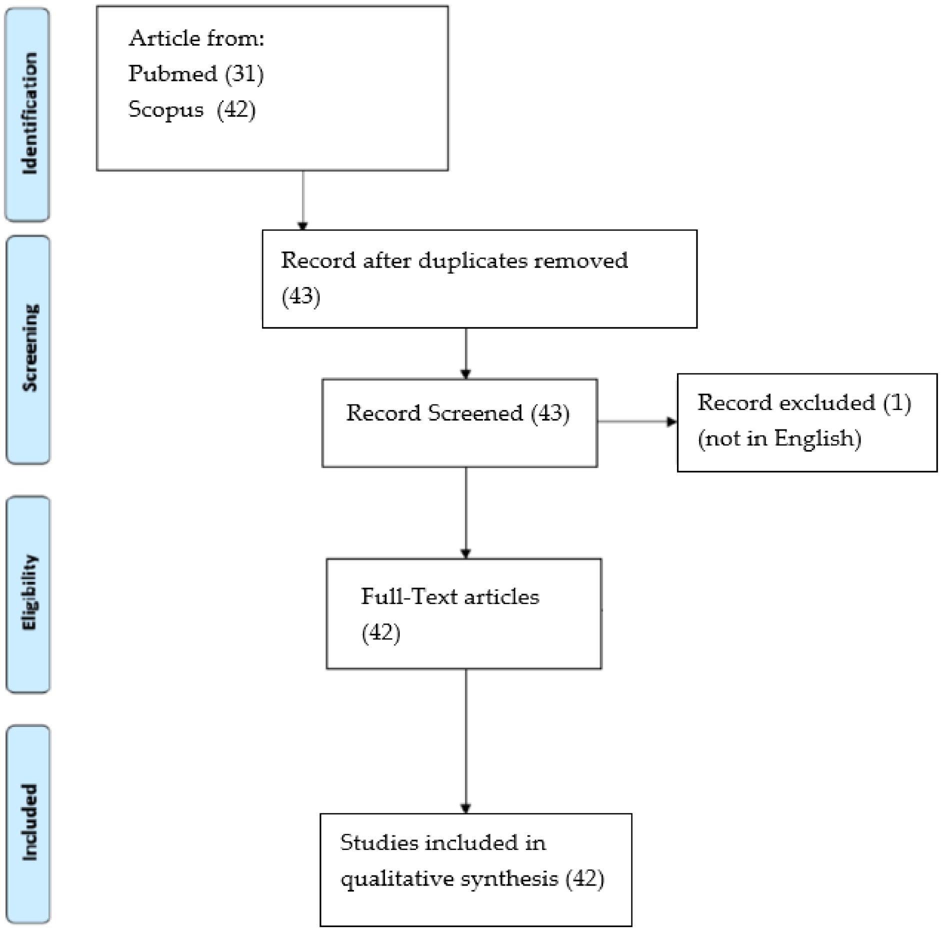

Figure 1. PRISMA Search flow results [14].

All the articles considered for the study are indicated in Table 1. The number of articles concerning this technique, and their topicality, all very recent, represent a great invitation to continue the research about BioHPP. Only two articles, in their conclusions, underline the negative aspects of this material or the lack of clinical evidence, not considering it to be on par with those conventionally used: Zoidis et al. affirmed "Due to the lack of solid clinical evidence, BioHPP should not be considered as a substitute framework material for a well-designed Cr-Co RDP" and Andrikopoulou et al. "Due to lack of clinical evidence, BioHPP cannot substitute the conventional metal ceramic or all ceramic materials; however, it can be used as an alternative treatment option" [3,15].

Table 1. Included studies characteristics.

Title and First Author	Objective	Year	Conclusions
Is the high-performance thermoplastic polyetheretherketone indicated as a clasp material for removable dental prostheses? Micovic D. et al.	To investigate the retention force of polyetheretherketone (PEEK) removable dental prosthesis clasps in comparison with a cobalt-chrome-molybdenum control group after storage in artificial saliva.	2020 [16]	The retention force values observed for PEEK materials indicate a potential clinical application, not influenced by manufacturing process. PEEK materials presented constant results also after artificial aging.
Comparative evaluation of BioHPP and titanium as a framework veneered with composite resin for implant-supported fixed dental prostheses Jin H.Y. et al.	The aim was to evaluate and compare the bond strength of modified PEEK (BioHHP) and titanium with a veneering composite resin and compare the marginal fit and fracture resistance of implant-supported screw-retained FDPs fabricated by using computer-aided design and computer-aided manufacturing (CAD/CAM) frameworks veneered with composite resin.	2019 [4]	The bond strength of BioHPP to composite resin was greater than that of titanium. CAD/CAM BioHPP frameworks exhibited good marginal fit and fracture resistance, it represent a suitable alternative to metal restoration.
Cytocompatibility of Titanium, Zirconia and Modified PEEK after Surface Treatment Using UV Light or Non-Thermal Plasma Guo L. et al.	The objective of this study was to compare the effects of UV light and NTP on machined titanium, zirconia and modified polyetheretherketone (PEEK, BioHPP) surfaces in vitro.	2019 [17]	UV light and oxygen plasma treatments may improve the attachment, proliferation and viability of soft tissue cells on machined titanium, zirconia and ceramic reinforced PEEK surfaces. These materials they offer excellent biocompatibility characteristics.
Fracture Resistance of Titanium, Zirconia, and Ceramic-Reinforced Polyetheretherketone Implant Abutments Supporting CAD/CAM Monolithic Lithium Disilicate Ceramic Crowns After Aging Atsü S.S. et al.	The aim of this study was to compare the effects of UV light and NTP on machined titanium, zirconia and modified polyetheretherketone (PEEK, BioHPP) surfaces in vitro.	2019 [18]	Promising fracture strengths and fracture types were found for the ceramic reinforced PEEK abutments with titanium base
A potential application of materials based on a polymer and CAD/CAM composite resins in prosthetic dentistry Jovanović M. et al.	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.	2021 [6]	These materials offer many advantages over traditional metal-ceramic materials, such as better aesthetics properties, biocompatibility, and less brittleness. 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.
Influence of fatigue loading on fracture resistance of endodontically treated teeth restored with endocrowns. Elashmawy Y. et al.	This in vitro study aimed to evaluate the influence of fatigue loading on fracture resistance of endodontically treated molars restored with endocrowns using different machinable blocks.	2021 [19]	Poly infiltrated ceramics should be considered as a proper material to be used as an endocrown material, also because of its ability to be restorable if failure occurs.

Table 1. *Cont.*

Title and First Author	Objective	Year	Conclusions
Retention of a telescopic overdenture on customized abutments after the simulation of 1 year in function Ramadan R. et al.	The aim of the study was to evaluate the retention of a BioHPP (biocompatible highperformance polymer) telescopic overdenture supported by customized abutments made from 2 different materials after the simulation of 1 year in function.	2021 [20]	BioHPP and titanium are both considered suitable materials for customized abutments to retain BioHPP telescopic implant overdentures.
Modified PEEK Resin Bonded Fixed Dental Prosthesis for a Young Cleft Lip and Palate Patient Andrikopoulou E. et al.	This clinical report presents the use of a modified poly etheretherketone material as an alternativematerial for the fabrication of resin-bonded fixed dentalprosthesis (RBFDP) framework.	2016 [15]	Due to lack of clinical evidence, BioHPP cannot substitute the conventional metal ceramic or all ceramic materials; however it can be used as an alternative treatment option.
Flexural strength of polymethyl methacrylate reinforced with high-performance polymer and metal mesh Ardakani Z.H. et al.	The present study aimed to evaluate the effect of high-performance polymer (BioHPP) and metal mesh reinforcement on the FS of a heat-cured poly methyl methacrylate (PMMA) acrylic resin.	2021 [21]	Accordingly, BioHPP is not a suitable substitute for metal reinforce to enhance the Fracture Strenght of PMMA denture base material.
Comparative evaluation of marginal and internal fit of endocrowns using lithium disilicate and polyetheretherketone computer-aided design—computer-aided manufacturing (CAD-CAM) materials: An in vitro study Godil A.Z. et al.	The primary research question was to investigate any statistically significant differences in the marginal and internal gap of endocrowns using PEEK or Lithium Disilicate for endocrowns.	2021 [22]	The current study shows a statistically significant difference in which lithium disilicate showed a better marginal and internal fit compared to PEEK. However, the marginal fit of both materials is within the clinical acceptable range. Hence, both the materials can be used as endocrown materials.
Wear behavior of current computer-aided design and computer-aided manufacturing composites and reinforced high performance polymers: An in vitro study Diken Turksayar A.A. et al.	To analyze the wear rate of computer-aided design and computer-aided manufacturing (CAD/CAM) composites, polyetheretherketones and glass ceramics.	2021 [23]	High performance polymers show less wear against natural enamel than ceramic and composite materials. The wear type of polyetheretherketone, which has high wear resistance and low elastic modulus, is also different from ceramic and composite materials.
Behavior of polyether-ether-ketone (PEEK) in prostheses on dental implants. A review. Blanch-Martínez N. et al.	The objective of this review is to know the characteristics of this material and thus assess its advantages and disadvantages in its possible applications in prostheses on dental implants.	2021 [24]	The main PEEK characteristics are due to its low elastic modulus, similar to that of bone, its low hardness, which will not cause an abrasion of the opposing tooth as occurs with the ceramic. We cannot conclude anything on the survival of prostheses made with PEEK after a time in the mouth.
Comparative prospective clinical evaluation of computer aided design/computer aided manufacturing milled BioHPP PEEK inlays and Zirconia inlays. Rajamani V.K. et al.	The aim of the present study was to clinically assess the performance of BioHPP PEEK material when used for inlay restoration and to compare it with widely used zirconia inlays.	2021 [25]	High level of accuracy of fit can be achieved in inlay restorations with use of BioHPP PEEK materials.

Table 1. *Cont.*

Title and First Author	Objective	Year	Conclusions
Retention of different CAD/CAM endocrowns bonded to severely damaged endodontically treated teeth: An in vitro study. Elashmawy Y. et al.	The aim of the present study was to assess the retention of endocrowns fabricated of different CAD/CAM materials.	2021 [19]	Within the limitations of this study, using lithium disilicate glass ceramics and resin-infiltrated ceramics as restorative materials to fabricate endocrowns to restore severely damaged endodontically treated teeth recorded significantly higher retention values.
Polyetheretherketone (PEEK) Post and Core Restorations: A 3D Accuracy Analysis between Heat-Pressed and CAD/CAM Fabrication Methods. Lalama M. et al.	The purpose of this study was to evaluate the accuracy of polyetheretherketone (PEEK) based post and core restorations using heat-pressed and computer-aided design and computer-aided manufacturing (CAD/CAM) methods.	2021 [26]	This study showed that heat-pressed PEEK post and core restorations resulted in higher accuracy when compared to the CAD/CAM method.
Comparison of the Bond Strength of Composite Resin to Zirconia and Composite Resin to Polyether Ether Ketone: An In Vitro Study Sarfaraz H. et al.	The aim of the study was to compare the shear bond strength of composite resin bonded to polyether ether ketone (PEEK) and zirconia, and also to evaluate the effect of thermocycling on the shear bond strength.	2020 [27]	The shear bond strength of PEEK is similar to that of zirconia. As an alternative to metal, BioHPP can thus be recommended as a framework to be veneered with composite resin.
The Effect of Surface Pretreatment and Water Storage on the Bonding Strength of a Resin Composite Cement to Modified PEEK. Spyropoulos D. et al.	The aim was to evaluate the bonding quality of bonding to polyether ether ketone (PEEK) after different surface treatments.	2020 [12]	Use of different conditioning protocols had a significant effect on the final bond strength of composite resin cement to PEEK surface
Retention force of polyetheretherketone and cobalt-chrome-molybdenum removable dental prosthesis clasps after artificial aging. Mayinger F. et al.	The aim is to examine the retention force of removable dental prosthesis (RDP) clasps made from polyetheretherketone (PEEK) and cobalt-chrome-molybdenum (CoCrMo, control group) after storage in water and artificial aging.	2021 [28]	Within the tested PEEK materials, PEEKmilled2 presented superior results than PEEK pressed. Artificial aging led to a significant decline in retention force for all PEEK-based materials
Suitability of Secondary PEEK Telescopic Crowns on Zirconia Primary Crowns: The Influence of Fabrication Method and Taper Merk S. et al.	The aim is to investigates the retention load (RL) between ZrO_2 primary crowns and secondary polyetheretherketone (PEEK) crowns made by different fabrication methods with three different tapers.	2016 [29]	PEEK may be a suitable material for removable prosthesis and a telescopic crown technique when used on zirconia crowns.
Wear Resistance, Color Stability and Displacement Resistance of Milled PEEK Crowns Compared to Zirconia Crowns under stimulated Chewing and High-Performance Aging Abhay S. et al.	This study aimed to compare the wear resistance, abrasiveness, color stability, and displacement resistance of zirconia and PEEK milled crowns.	2021 [30]	The PEEK crowns showed minimal abrasion, better stress modulation through plastic deformation, and good color stability, which makes it a promising alternative to zirconia for fabrication of the crown.

Table 1. *Cont.*

Title and First Author	Objective	Year	Conclusions
Optical Properties and Color Stability of Dental PEEK Related to Artificial Ageing and Staining Porojan L. et al.	The aim of this study was to investigate the long-term effect of the combined action of ageing and immersing solutions on the optical properties and color stability of PEEK material, related to surface processing (polishing or glazing).	2021 [31]	PEEK glazing has a favorable effect on surface roughness and opalescence, irrespective of the artificial ageing or staining protocols. Artificial ageing damages the color stability and roughness of PEEK.
Comparison of various 3D printed and milled PAEK materials: Effect of printing direction and artificial aging on Martens parameters. Prechtel A. et al.	The aim of this study was to investigate the effect of artificial aging on the Martens parameters of different 3D printed and milled polyaryletherketon (PAEK) materials.	2020 [32]	Additive manufacturing of PEEK for dental application sseems promising, but still needs further investigation to understand material and process influences better.
In-vitro fatigue and fracture testing of CAD/CAM-materials in implant-supported molar crowns. Preis V. et al.	The aim of the study is to investigate the fatigue and fracture resistance of different CAD/CAM-materialsas implant- or tooth-supported molar crowns with respect to the clinical procedure(screwed/bonded restoration).	2017 [33]	Conclusion based on the present in vitro results, most CAD/CAM materials, except for polyether ether ketone with composite pasteveneers, may be applied in implant-supported crowns with-out restrictions. The insertion of a screw channel resulted in a total failurerate of polyether ether ketone crowns with composite pasteveneers, and reduced fracture resistance for two compositematerials (COB, COH).
Influence of different materials on retention behavior of CAD/CAM fabricated bar attachments. Abdelrehim A. et al.	The aim was was to assess the retentive behavior of implant overdentures and the loss of retention from clip wear when used with computer-aided design and computer-aided manufacturing (CAD/CAM) fabricated bar attachments from cobaltchromium (Co-Cr), zirconia (ZrO_2), and BioHPP to identify the optimal material in terms of minimal loss of retention and minimal wear.	2021 [34]	BioHPP is a candidate for replacing Co-Cr and ZrO_2 for fabricating bar attachments.
Retention force of differently fabricated telescopic PEEK crowns with different tapers. Stock V. et al.	The aim of this study was To assess the retention force between primary and secondary PEEK crowns made by different fabrication methods.	2016 [35]	Milled PEEK crowns with a 0° taper showed the lowest retention force values, whereas milled PEEK crowns with a 2° taper showed the highest retention force values. For pressed PEEK crowns the taper angle had no impact on retention force.
The Use of a Modified Poly-Ether-Ether-Ketone (PEEK) as an Alternative Framework Material for Removable Dental Prostheses. A Clinical Report Zoidis P. et al.	The aim of this study eas to evaluate fot the first time BioHPP as an alternative framework material for removable dental prostheses.	2016 [3]	Due to the lack of solid clinical evidence, BioHPP should not be considered as a substitute framework material for a well-designed Cr-Co RDP.

Table 1. *Cont.*

Title and First Author	Objective	Year	Conclusions
Modified PEEK resin-bonded fixed dental prosthesis as an interim restoration after implant placemen Zoidis P. et al.	The aim of this study was to evaluate modified PEEK resin-bonded fixed dental prosthesis as an interim restoration after implant placement	2016 [36]	PEEK has a low specific weight that permits the fabrication of lighter prostheses, providing high patient satisfaction and comfort during function.
Denture base adaptation, retention, and mechanical properties of BioHPP versus nano-alumina-modified polyamide resins Emera R.M.K. et al.	The present study aimed to evaluate the mechanical properties, adaptation, and retention of alumina nanoparticles (Al_2O_3 NPs) modified polyamide resin versus BioHPP (high-performance polymer) denture base materials.	2021 [37]	BioHPP and Al_2O_3 NP-modified polyamide resin could be used as a promising alternative denture base material with good adaptation, retention, and mechanical properties.
Comparison of the strain developed around implants with angled abutments with two reinforced polymeric CAD/CAM superstructure materials: An in vitro comparative study Omaish H.H.M. et al.	The aim is to assess the strain developed around implants with angled abutments (15 and 25 degrees) of biocompatible high-performance polymer (BioHPP) and reinforced nanohybrid polymer with a multilayered glass fiber (TRINIA) superstructure under axial and oblique loading	2022 [38]	The strain developed around dental implants was significantly affected by the superstructure material. The microstrain was considerably higher when the implant abutment angulation increased. When a 45-degree loading direction was used, this tendency became more pronounced.
Review of Different Materials that can be CAD/CAM Processed Description, chemical composition, indications in dentistry areas Popa D. et al.	The objective of this paper is to inform on the indications, appearance and advantages offered by each category of materials used in CAD/CAM technique for different prosthetic restorations. We can choose from available materiales including glass ceramics, nano ceramics, zirconia, hybrid ceramics, BioHPP, in blocks or disks form.	2019 [39]	BioHPP is a high performance polymer developed especially for intra-oral use. Indications in dentistry areas: single crowns, bridges (maximum 2 pontics), adhesive bridges (Maryland), suprastructures with or without frictional elements, secondary parts for telescopic crown technique and bar suprastructures, supraimplant restorations, crowns and bridges (cemented or screwed), primary crowns, removable suprastructures, Toronto bridge.
Comparison of Two Evaluating Methods for Establishing the Marginal Fit on Four Heat—Pressed Resin Inlays. Baciu S. et al.	The aim is to compare two investigation methods, a bi-dimensional and a three-dimensional technique, by examining the marginal fit of pressed resin (BioHPP) inlays.	2018 [40]	Composite inlays are an alternative with superior results offering good esthetic results and longevity compared to Fillings. BioHPP provides very good clinical results due to of the structure but also due to of the polymerization method, namely heat pressing. It has no abrasive effect on the remaining teeth, it has white color suitable for fully anatomical use, and it insures no ion exchange in the mouth, no discoloration along with excellent stability and optimal polishable properties.
Evaluations of Two Reinforced Polymers Used as Metal-FreeSubstructures in Fixed Dental Restorations Biris C. et al.	The purpose of the study was to present the results of the comparative clinical trials referring to the use of BioHPP and Trinia resins as core in fixed prosthetic rehabilitation.	2018 [41]	Both types of these materials exhibit a certain degree of elasticity and have numerous advantages.

Table 1. *Cont.*

Title and First Author	Objective	Year	Conclusions
Three-dimensional Marginal Evaluation of Two Pressed Materials Using Micro-CT Technology Baciu S. et al.	The aim of this study is to compare themarginal fit of two different kind of pressed materials: a partially crystalline thermoplastic resin reinforced with ceramic particles (BioHPP) and lithium disilicate (Max), through the use of the microCT technique.	2017 [42]	A significant statistical difference was found between the marginal gap size obtained for BioHPP and Emax inlays ($p < 0.001$). For the Emax inlays the marginal gap had an average of 72 µm, while for BioHPP the average was 94 µm.
The Benefits of Polyether-Ether-Ketone Polymers in Partial Edentulous Patients Pacurar M. et al.	The purpose of this article is to present the results of the clinical trials referring to the benefits of skeleton prostheses wearers'patients with BioHPP framework.	2016 [43]	This PEEK type of dental material represent a beneficial new acquisitionfor the partial edentulous patient.
The Advantages of BioHPP Polymer as Superstructure Material in Oral Implantology Bechir M. et al.	The purpose of this article is to present the results of the clinical trials referring to the advantages of BioHPPpolymer as superstructure in oral implantology.	2016 [44]	BioHPP for fixed prosthetic restoration, like superstructure on dental implant abutments present many advantages.
A new material for fixed implant-supported rehabilitations Di Iorio E. et al.	The aims of this study were to describe the implant-supported rehabilitation of a female patient presenting a totally edentulous maxilla and to highlight the clinical features of a new polymer used for the final restoration.	2015 [45]	This new polymer material, introduced in prosthetic dentistry in 2013, may substitute metal or zirconium thanks to its extraordinary flexibility, great resistance, low weight, optimumpolishing features and low plaque affinity.
Short-term comparative evaluation of BioHPP and cast cobalt–chromium as framework for implant supported prostheses: A split mouth clinical randomized trial Amer M. et al.	The purpose of this parallel randomized clinical trial was to evaluate the effects of BioHPP versus cobalt–chromium (Co–Cr) frameworks in screw-retained implant-supported fixed dental prostheses (FDPs) on peri-implant soft and hard tissues clinically and radiographically	2021 [46]	BioHPP framework represents a viable nonmetallic alternative to cast Co–Cr framework, shown by good soft and hard tissue responses.
Evaluation of biocompatibility of veneered Bio HPP and veneered lithium disilicate crowns in anterior zone (Randomized controlled clinical trial) Odeh E. et al.	The aim of the present study is to evaluate the biocompatibility of Bio-High Performance Polymer (Bio HPP) crowns veneered with Visio-Ling versus e.max crowns veneered with e.max veneering system.	2021 [47]	Bio HPP showed a higher significant difference PD than e.max.
One Year Clinical Evaluation of Milled BioHPP (PEEK) Versus Zirconia Veneered Single Crowns (RCT-one-year Evaluation) Badran A.R. et al.	BioHPP PEEK single crowns as a intervention to evaluate the marginal integrity and fracture.	2021 [48]	BioHPP PEEK is a promising material for dental application and it has been proposed for other prosthodontic applications such as fixed prostheses and removable prostheses.
Clinical Application of PEEK as a Provisional Fixed Dental Prosthesis Retained by Reciprocated Guide Surfaces of Healing Abutments During Dental Implant Treatment Kwan J.C. et al.	The aim is to evaluate BioHPP for use in provisional fixed dental prostheses (FDPs) that can be retained by reciprocated guide surfaces of hexagonal-shaped healing abutments during dental implant treatment.	2021 [49]	The results from this study suggest that PEEK can be a suitable material for use in provisional Fixed Dental Prosthesis during dental implant treatment.

Table 1. *Cont.*

Title and First Author	Objective	Year	Conclusions
Comparative Study Clarifying the Usage of PEEK as Suitable Material to Be Used as Partial Denture Attachment and Framework. Sadek S.A. et al.	This consideration aimed to verify the convention of polyether ether ketone (PEEK) material as an attachment.	2019 [50]	Utilization of PEEK material as both an attachment and framework decline the strains performed around the abutment teeth and over the edentulous ridge.
Comparative Study on the Degree of Bacterial Biofilm Formation of Dental Bridges Made from Three Types of Materials Bolat M. et al.	The aim of this study was to compare the biofilm formation on three types of dental crown materials using adenosine triphosphate (ATP) driven bioluminescence as an innovative tool for the rapid chairside enumeration of oral bacteria and assessment of oral hygiene.	2019 [51]	The lowest value was shown for Zirconia, comparing with ceramics and BioHpp, but in time we have seen the increase of ATP for all three dental crown materials.

4. Discussion

Peri-implant health is extremely delicate, and strongly correlated with the type of prosthesis, the hygiene of the product and the control of the load distributed at the bone level [10,16]. It is now evident in the literature that the levels of inflammation of the peri implant sulcus, also as a function of the different biological width and therefore of the different implant type, must be maintained and controlled, and to favor this it is necessary that the implant supported prosthesis guarantees excellent marginal closures, cleanable profiles, and does not favor the accumulation of plaque [52–54]. The shock absorbance as a feature of this implant material is extremely relevant, and allows for performing an implant rehabilitation, even complete, with interesting mechanical and biological characteristics: It is known that overload cannot directly cause peri-implantitis, but participates as a factor, together with the levels of inflammation that it maintains higher as a stimulus for bone resorption, in the development of implant pathology [20].

CAD/CAM BioHPP® frameworks exhibited not only shock absorbing, but also good marginal fit and fracture resistance and good retention force [4,21].

BioHPP® demonstrates a high biocompatibility, even superior to Zirconia in certain characteristics, and can be superimposed on the materials commonly used for implant restorations [6,22].

Use of different conditioning protocols had a significant effect on the final bond strength of composite resin cement to PEEK surface, but always at an excellent level, guaranteeing a perfect combination between the two materials [12].

Regarding the mechanical characteristics and physical properties of BioHPP®, promising fracture strengths and fracture types were found for the ceramic reinforced PEEK abutments with titanium base [23]. Ardakani et al. researched differently than other authors, but about a different and more complex application of BioHPP®; the state "BioHPP is not a suitable substitute for metal reinforce to enhance the Fracture Strength of PMMA denture base material" [21]. Also, wear behavior of the BioHPP® is extremely suitable for clinical use in dentistry [25]. The main PEEK characteristics are due to its low elastic modulus, similar to that of bone, its low hardness, which will not cause an abrasion of the opposing tooth, which does occur in the case of ceramic [26]. Rasheed et al. state that the shear bond strength of PEEK is similar to that of zirconia, showing the advantage that with the right surface treatments it is also the best adhesive solution [12,27]. Furthermore, the PEEK crowns showed minimal abrasion, better stress modulation through plastic deformation, and good color stability, which makes it a promising alternative to zirconia for fabrication of the crown [28–31]. PEEK has a low specific weight that permits the fabrication of lighter prostheses, providing high patient satisfaction and comfort during function [32].

For this reason, BioHPP could be used as a promising alternative denture base material with good adaptation, retention, and mechanical properties [33].

The study of Lalama et al. showed that heat-pressed PEEK post and core restorations resulted in higher accuracy when compared to the CAD/CAM method [26]. BioHPP PEEK can be fabricated via CAD/CAM technology by milling PEEK blanks. It can also be pressed by using granular or pellet-shaped PEEK [50–54].

Furthermore, for the application of this material in the production of endocrowns, the evidence is numerous and in agreement. Poly infiltrated ceramics should be considered as a proper material to be used as an endocrown material; furthermore, they allow for easy reprocessing in case of failure [35]. Lithium disilicate showed a better marginal and internal fit compared to PEEK. However, the reinforced PEEK marginal fit is also within the clinical acceptable range [36]. The results are also clinically acceptable in comparison with Zirconia inlay restorations [37]. BioHPP provides very good clinical results due to the structure, but also the polymerization method, namely heat pressing. It has no abrasive effect on the remaining teeth, has white color suitable for fully anatomical use, and insures no ion exchange in the mouth, no discoloration, excellent stability, and optimal polishable properties [45]. However, lithium disilicate remains the gold standard of this type of rehabilitation [38]. Therefore, also for this application, BioHPP® has proven to have excellent characteristics and clinical reliability.

Regarding the retention and wear characteristics of this material, the results are excellent, guaranteeing long-term good results both in terms of resistance and wear [38,39].

PEEK may be a suitable material for removable prosthesis and a telescopic crown technique when used on zirconia crowns [39]. For its future applications, it turns out to be an excellent material also to replace the Cr-Co bars, and considering its positive bond with the composite materials previously highlighted, it turns out to be of a high level [41–43].

Regarding Zoidis et al. and Andrikopoulou et al., who expressed less positive comments than other authors, it is also necessary to underline that these are two of the first works published on this topic (5 years ago), and are among the oldest included in the study. This latter fact may be an indication of how the consideration of these materials has changed in just 5 years [3,15].

Furthermore, excellent stability and optimal polishable properties allow the material to have a low affinity for plaque, which hardly aggregates as a biofilm on its mirror-polished surface [45,52–55].

The limitation of this review is that the presence of a few articles, most of which were published over the last two years, and the little clinical follow-up, did not allow for the execution of a systematic review with meta-analysis.

By improving the aesthetics of this material and its durability with unchanged characteristics greater than that of long-term provisional materials, it could in the near future be used as prosthetic materials for definitive restorations.

The authors, in light of the analysis of the articles included in this review, consider this material to be not only extremely interesting for the future, but with characteristics suitable for clinical application already today, in particular for endocrowns, small adhesive bridges, temporary prostheses, and for immediate loads on implant restorations.

5. Conclusions

BioHPP® is an extremely interesting material both for its mechanical characteristics, for its extreme biocompatibility, and above all for its clinical adaptability in dentistry. The excellent aesthetics, as well as the possibility of simple reprocessing of the restorations made with this material, invite its clinical application. The use of BioHPP® is indicated in fixed prostheses for:

- single crowns
- endocrowns
- bridges with up to two pontics
- bonded bridges (Maryland bridges)

And in removable prostheses for:

- superstructures with or without friction elements
- secondary parts in the presence of bars
- individual abutments
- Toronto Bridge

What makes this material extremely interesting is that it achieves a perfect balance between elasticity, stiffness, weight and breaking strength, physiologic integration, and resistance to plaque with a perfectly polished surface.

In light of the evidence that emerged from this article, the authors suggest the use of this material for temporary prostheses production, especially with immediate loading protocols. The main indication remains the application in implant prosthesis, but increasing attention must be paid to conservative restorations on teeth.

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