

A review of PEEK polymer's properties and its use in prosthodontics

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SUMMARY

Objective. The aim of this study is to review polyether ether ketone (PEEK), its characteristics and use in prosthodontics.

Material and methods. Information search for articles about PEEK and its use in prosthodontics between January 2010 and April 2017 was conducted in Medline via PubMed, Science direct, Wiley online library as well as the Web search Google Scholar sources. Twelve full text articles were selected and used in this review.

Results. 143 articles were found in the database using keywords: PEEK, prosthodontics, dentistry. Data on the suitability of PEEK polymer were organized according to mechanical, chemical, physical properties and PEEK surface preparation.

Conclusions. PEEK polymer is suitable to use in prosthodontics. However, there are not enough statements about complications, biofilm formation on PEEK surface and its resistance to compression. More research should be done to find out the results.

Key words: PEEK, prosthodontics, dentistry.

INTRODUCTION

Advance in dentistry and development of technologies can be reached by improving materials. Biocompatibility, low plaque affinity, good aesthetics and characteristics close to dental structure are essential to modern materials used in advanced dentistry. It helps to rebuild the defects of the teeth and dentition and pleases demanding patients.

Insufficient oral hygiene and a lack of prevention cause increase of dental caries and periodontal problems. According to World Health Organization (WHO) 2012 data 60-90% of school children and nearly 100 % of adults have dental cavities which untreated may destroy dental tissues (1). Dental defects can be restored by using fixed or removable restorations. For the best rehabilitation of masticatory function it is indicated to use scientifically approved and safe materials. This article reviews one of the new dental materials - polyether ether ketone (PEEK), its characteristics and use in prosthodontics.

PEEK ($-C_6H_4-OC_6H_4-O-C_6H_4-CO-$)_n is a semi-crystalline linear polycyclic aromatic polymer. In 1978 it was developed by a group of English scientists. Later PEEK was commercialized for industrial applications. By the late 1990s, PEEK became an important high-performance thermoplastic candidate for replacing metal implant components, in vertebral surgery as a material of the interbody fusion cage. With the emergence of carbon fiber reinforced PEEK (CF/PEEK), this new composite material was exploited for fracture fixation and femoral prosthesis in artificial hip joints (2).

PEEK is white, radiolucent, rigid material with great thermal stability up to 335.8° C (3). It is non allergic and has low plaque affinity (4-6). Flexural modulus of PEEK is 140-170 MPa, density – 1300 kg/m³ and thermal conductivity 0.29 W/mK (4, 6, 7). PEEK's mechanical properties do not change during sterilization process, using steam, gamma and ethylene oxide (2, 8). Young's (elastic) modulus of PEEK is 3-4 GPa (7, 9). Young's modulus and tensile properties are close to human bone, enamel and dentin (10). Polyether ether ketone is resistant to hydrolysis, non-toxic and has one of the best biocompatibility (11, 12). Special chemical structure of PEEK exhibits stable chemical and physical properties: stability at high temperatures (like sterilization processes), resistance to most substances apart from

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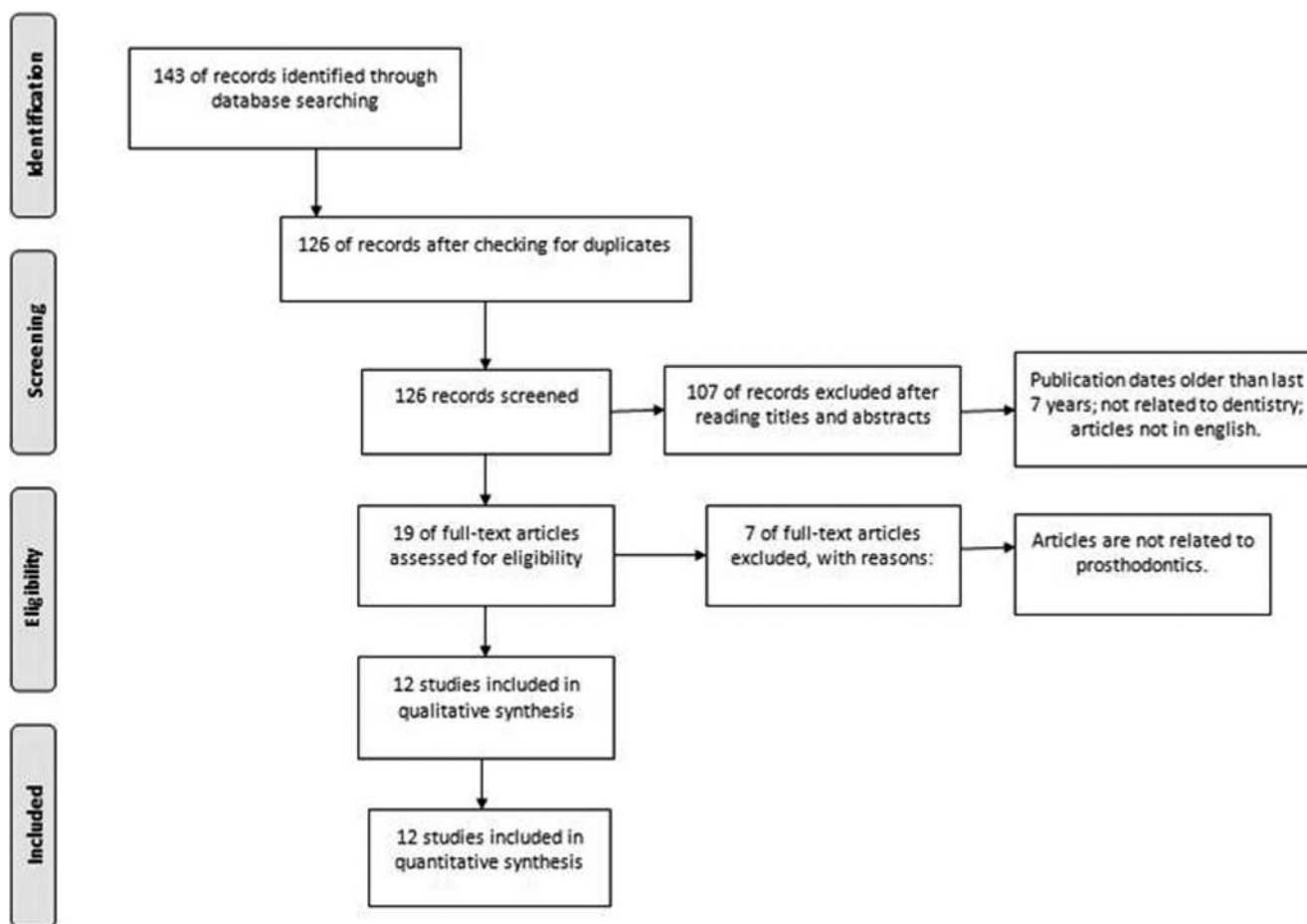


Fig. Diagram of the literature search strategy

concentrated sulfuric acid and wear-resistance (2). Lieberman *et al.* (13) *in vitro* research comparing PEEK, poly methyl methacrylate (PMMA) and composite resin showed that PEEK has the lowest solubility and water absorption values. As PEEK is quite new material in dentistry comparing to composite, ceramics or zirconia, it is important to find out and summarize its properties.

The aim of this review is to evaluate PEEK polymer and its use in dentistry.

MATERIAL AND METHODS

The literature search covered the following databases: Medline via PubMed, Science direct, Wiley online library as well as the Web search Google Scholar sources dated between January 2010 and April 2017. The titles and abstracts were reviewed. Some study subjects were not suitable for this review, others were mentioned in different databases. In the end, twelve full text articles fulfilled the inclusion criteria (Figure 1).

Inclusion criteria: exclusively English articles about dental prostheses from PEEK or modified PEEK were included, despite of the methods of

manufacture, surface modifications, the kind of investigation (*in vitro* or *in vivo*), type of scientific articles (case reports, original researches, review articles). The period of selected articles was from January 2010 until April 2017.

Exclusion criteria: articles not related to prosthodontics, articles written not in English language, articles older than seven years.

RESULTS

143 articles were found in the database using keywords: PEEK, prosthodontics, dentistry. The studies over 7 years old were not included. 20 studies included reading titles and abstracts. Twelve full text articles were selected and used in this review. The selected studies were divided into groups according to the type of the study: properties and its suitability in prosthodontics and PEEK's surface conditioning using various adhesive systems. The analysis of the articles shows PEEK's characteristics and its suitability in prosthodontic treatment. Data were systematized in assessing kind of mechanical, chemical, biological properties (Table 1). Data of evaluation of shear bond strength of PEEK to den-

tal tissues using various surface conditioning and adhesive systems (Table 2).

DISCUSSION

PEEK is quite new material in prosthodontics. Comparing to the metals used in dentistry, PEEK is more aesthetic, stable, biocompatible, lighter and has reduced degree of discoloration (14, 15). This makes it more attractive to patients with high aesthetic requirements. However, due to its grayish-

brown color PEEK is not suitable for monolithic aesthetic restorations of anterior teeth (16). More aesthetic material like composite should be used for coating to get an aesthetic result. In literature many surface conditioning methods of PEEK are offered to improve bonding with resin composite crowns. Air abrasion with and without silica coating creates wettable surface, but etching with sulfuric acid makes rough and chemically processed surface (4, 17). Low energy of PEEK surface creates resistance to chemical processing. Uhrenbacher *et*

Table 1. Data associated with the lateral (direct) sinus floor elevation surgery

Author of the article	Year	Properties			Applications of PEEK in prothodontics
		Mechanical	Chemical	Biological	
Ma R <i>et al.</i> [2]	2014	Elastic modulus~8.3 GPa	Resistant to corrosion	Biocompatible	Component parts of implants
Najeeb S <i>et al.</i> [4]	2016	Tensile strength 80 MPa; Young's modulus 3-4 GP; CFR-PEEK 120 MPa	-	Non allergic; Has low plaque affinity	Implant abutments; Fixed crowns, fixed bridges; Removable dentures and components
Vaezi M <i>et al.</i> [5]	2015	-	Resistant to hydrolysis	Non allergic; Has low plaque affinity	Component parts of implants
Zoidis P <i>et al.</i> [6]	2015	-	-	Non allergic; Has low plaque affinity; Biocompatible	An alternative framework material for removable partial dentures
Garcia-Gonzalez D <i>et al.</i> [10]	2015	Elastic modulus 3.6 GPa; Density 1300 kg/m ³	Thermal conductivity 0.29 W/mK	-	Component parts of implants
Sheiko N <i>et al.</i> [8]	2016	-	-	Biocompatible	Component parts of implants
Schmidlin PR <i>et al.</i> [17]	2010	-	-	Biocompatible	Fixed prosthesis: temporary abutment for implants, crowns
Tannous F <i>et al.</i> [14]	2012	Tensile strength 97 MPa; Elastic modulus 4 GPa.	-	-	Partial removable dentures: thermoplastic resin clasps
Monich PR <i>et al.</i> [3]	2017	-	The glass transition temperature 143°C; The crystalline melt transition temperature 343 °C	Biocompatible	Component parts of implants
Schwitalla A <i>et al.</i> [9]	2013	Elastic modulus 3,6 GPa; Carbon fiber-reinforced PEEK (CFR-PEEK) obtain an elastic modulus of 17.4 GPa similar to that of cortical bone	-	-	Component parts of implants
Xin H <i>et al.</i> [7]	2013	Flexural yielding strength 165 MPa; Young's modulus 3.7 GPa	-	-	Component parts of implants
Zhou L <i>et al.</i> [12]	2014	-	-	Biocompatible	Component parts of implants : abutments, healing caps; Fixed protheses.

al. (18) investigated the modification of the surface strength of PEEK crowns adhesively bonded to dentin abutments. The highest values were found for the airborne-particle abrasion and sulfuric etched groups, and crowns adhesively pretreated with Signum PEEK bond and "visio.link" adhesive system. The results of Hallmann *et al.* research show that abraded PEEK surface with 50 µm alumina particles followed by etching with piranha solution lead to the highest tensile bond strength when Heliobond was used as adhesive (15). All these investigations confirm that resin composites can be used as a covering material of the PEEK frames. However, it is dangerous to use concentrated sulfuric acid in clinical practice.

Mechanical properties of the PEEK are similar to dentin and enamel. Thus it has superiority over metal alloys and ceramic restorations. CAD-CAM milled PEEK fixed prostheses' resistance to fracture is 2354N. It has higher resistance than lithium disilicate ceramic (950N), aluminium (851N) or zirconia (981-1331N) (19). However, there are no clinical data about PEEK's abrasion with other materials such as metal alloys, ceramics, dentin or enamel. Mastication cyclically loads the teeth with a 400 N force. As PEEK has high fracture load resistance it is suitable for producing frames. High fracture resistance is also stated in Stawarczyk *et al.* publications. A mean fracture relative load was 1383 N of 3-unit PEEK frameworks without veneering (16).

Despite high fracture resistance, PEEK is relatively weak mechanically in homogenic form. Tannous *et al.* (14) *in vitro* research showed that clasps made of PEEK have lower resistance forces than the ones made from cobalt - chrome. Scientists have searched for combinations with other materials, to improve PEEK's properties. Modified PEEK containing 20% ceramic fillers known as BioHPP

(Bredent GmbH Senden, Germany) is non allergic and has high biocompatibility. Possibility of corrections, excellent stability, great optimal polishable properties and aesthetic white shade of BioHPP help to produce high-quality prosthetic restorations (4). BioHPP has a great potential as framework material. This is a good alternative to Cr-Co frames for the patients with high aesthetic requirements. But in clinical situations the results might be different.

Individual abutments on implants can be milled of PEEK. They are usually used for temporary restorations. Randomized controlled clinical trial showed, that there is no statistically significant difference between PEEK and titanium abutments, causing bone resorption or inflammation. Moreover, the attachment of oral microorganisms to PEEK abutments is comparable to those made of titanium, zirconia and poly methyl methacrylate. Therefore, PEEK is a promising alternative to titanium abutments (4). Comparing to titanium, the polymer could exhibit less stress shielding, but very limited inherent osteoconductive properties (4). This leads to negative impact in osseointegration process.

Nowadays, there are many combinations of PEEK with other materials such as fibers, carbon or ceramics. Due to complexed chemical structure and poor wetting capabilities of PEEK it is hard to prepare its surface in order to increase bond strength and bonding with composites. For good functioning, the surface of PEEK restorations has to be covered by other material like resin composites or lithium disilicate. The best surface processing option is still not found. Moreover, composite as a coating material of the PEEK may degrade with time. So if the polymer frame remains stable, it is necessary to renew the coating material. These are extra expenses to the patient. Unfortunately, there was not enough clinical research made to prove PEEK's

superiority over other materials. There is still not enough information stated about complications, biofilm formation on PEEK surface and its resistance to compression. Even so, PEEK is being used in manufacturing fixed restorations (18), dental implants, individual abutments, removable prostheses and their parts (4) and even maxillary obturator prostheses (20).

Table 2. Effect of sinus membrane perforations on the complications

Author of the article	Year	Preparation of PEEK surface		
		Surface conditioning (prepare)	Adhesive system	Shear bond strength (MPa)
Schmidlin PR <i>et al.</i> [17]	2010	Sulfuric acid 96%	Heliobond	18.2±5.4
			Relyx™ Unicem	19.0±3.4
		Sandblasting 50 µm	Heliobond	13.5± 2.4
Zhou L <i>et al.</i> [12]	2014	Sulfuric acid 98 %	SE Bond/Clearfil AP-X™	8.7 ± 0.2
			Relyx™ Unicem	7.4 ± 0.6
		Hydrofluoric acid 9.5%	SE Bond/Clearfil AP-X™	2.8 ± 0.2
			Relyx™ Unicem	0
Sandblasting 50 µm	Relyx™ Unicem SE	1.4 ± 0.2		
	Bond/Clearfil AP-X™	5.3 ± 0.6		
		Sandblasting 100 µm	Relyx™ Unicem	0

CONCLUSIONS

PEEK is an attractive modern material to use in prosthodontics. Due to its favorable chemical, mechanical and physical properties it is used in producing fixed and removable prostheses. However, more clinical

research is necessary to find out the situation, because most of the studies have been carried out *in vitro*.

STATEMENT OF CONFLICTS OF INTEREST

The authors state no conflict of interest.

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