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Review Article

Can High Performance Polymers Replace Traditional Alloys in Dentistry?

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Abstract

With increasing knowledge about aesthetics and restoration of teeth, the rate of partial edentulism is increasing day by day. Since ages, alloys have been the material of choice to restore teeth. But they have always been associated with an issue of unaesthetic appearance. Apart from this, as we are moving to a more sustainable life, biocompatibility of these alloys has also become a concern and need of the hour. Therefore, there is an urgent need for materials which are friendlier to our body. Hence, high performance polymers can be one option to replace these alloys. These polymers are basically superior types of thermoplastics which have operating temperature above 150°C. They are generally manufactured using milling process. There are different types of high-performance polymers used in medicine and dentistry. Out of those, mainly three types of polymers ae used in dentistry which are PEEK, PEKK and AKP.

Keywords: Dental Alloys; High Performance Polymers; PAEK; PEEK; PEKK; AKP

Abbreviation

PAEK: Polyaryletherketone; PEEK: Polyetheretherketone; PEEG: Polyether Ethylene Glycol PEG: Polyethylene Glycol; PEKK: Polyetherketone ketone; AKP: Aryl Ketone Polymers

Introduction

According to a prediction done by the United Nation, by year 2050, around one third of the global population will be represented by edentulous patients who are over the age of 60 years [1]. For decades, cast metal restorations are the treatment of choice for partial edentulous patients. These are generally fabricated from dental alloys such as type IV gold, Co-Cr and Ni alloys [2]. But these alloys have several limitations such as lacking aesthetic ability due to presence of metals, galvanism, production of biofilm and osteolysis of the adjacent teeth [3]. On the basis of a study, O'Donnell., *et al.* [4]. in 2016 concluded that such prosthesis can harbour *Streptococcus pneumonia* which is the main causative agent of respiratory tract infections like pneumonia. Apart from these, there are also issues related to their shrinkage due to casting [5]. In 2001, Rud and Rud [6] has also described that there are 243 different types of errors which occur during fabrication of removable partial denture. Hence, there is an urgent need to replace these dental alloys with other alternatives. High performance polymers are being the most important and common option to do so.

High performance polymers

These are superior type of thermoplastics with an operating temperature of more than 150°C [7]. These polymers are manufactured and supplied in form of discs or pucks which undergoes milling process as can be seen in figure 1 [8]. Additive and subtracting manufacturing techniques have made it possible to use these materials in dentistry [9].

Figure 1: Milled polymer-based framework. (Source- Akl, M.A. and Stendahl, C.G.,2022).

There are variety of high performance polymers being used in dentistry. Below is the classification of these.

S No.	CONVENTIONAL POLYMERS	HIGH PERFORMANCE POLYMERS
1	Methyl methacrylate (MMA)	PEEK
2	2-Hydroxyethyl methacrylate (HEMA)	Polyether ethylene glycol (PEEG)
	2,2-bis[*p*-(2-hydroxy-3-methacryloxypropoxy) phenylene]propane	Polyethylene glycol (PEG)
3	1,6-bis(methacryoxy-2-ethoxycarbonylamino)-2,4,4-trimethylhexane	Bioglass
4	Triethylene glycol dimethacrylate	

Table 1: Different types of polymers used in dentistry. (Source- Wiesli and Özcan, 2015).

History

Previously, in 1980s and 1990s, polymethoxymethylene (POM) and polyamides were used for RPD framework. POM is a thermoplastic technomer which is composed of methyl groups interlinked by oxygen molecules [10]. It is also known as acetal resin. Similarly polyamides are also thermoplastic group of polymers with high strength and flexibility. But, both these polymers are associated with increased harbour of bacteria and have high polymerisation shrinkage which does not make them material of choice for RPDs [11].

Thereafter, in order to find a better material, different types of high performance polymers were developed. Among these new materials, most of them belongs to polyaryletherketone (PAEK) family. They mainly comprise of three elements namely- aryl, ether, and ketone molecules which are arranged in various forms such as aromatic or semi-crystalline form. PEEK and PEKK are two common members of this group which are being used to replace dental alloys in rpd fabrication [12].

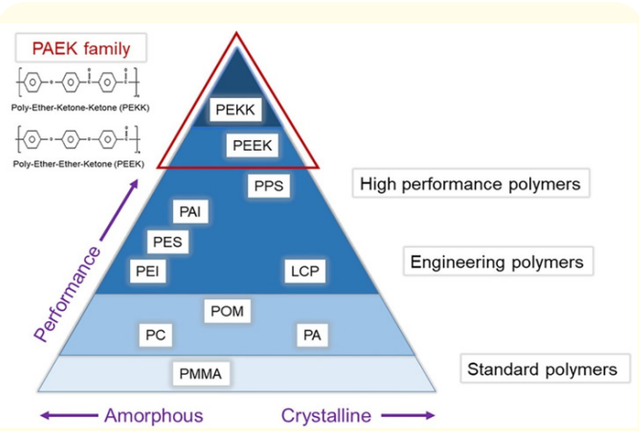

Figure 2: Pyramid of Polymers. (Source- Alqurashi., et al, (2021).

Polyetheretherketone (PEEK)

It is a polyaromatic thermoplastic hpp which is present in semi-crystalline form. It was introduced in engineering by Victrex PLC and later on by Imperial chemical industries in 1980s. After two decades, this material was proposed for biomedical applications and implants by Victrex under the name PEEK OPTIMA [13].

Structure of PEEK

It is an odourless and colourless organic thermoplastic with a backbone of ether and ketone functional groups which are bonded tightly to aryl rings. It is mainly made up of single monomer. At higher temperature, it attains distinct mechanical and chemical behaviour which makes it superior among other group of polymers. It has a simple structure with definite length and chemical composition. This helps in providing it better stability at higher temperatures [14]. It is synthesized mainly by alkylization of bisphenol salt. On cooling, it shows two different phases. One end of this process is crystalline in nature which controls thermal processing while another is amorphous [7].

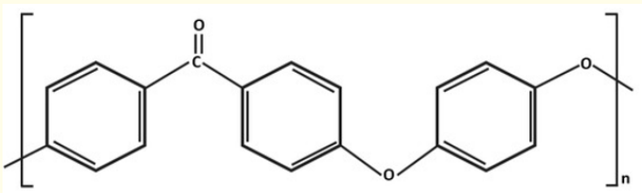

Figure 3: Structure of PEEK. (Source- Rahmitasari., et al, 2017).

Production of PEEK

Two processes are involved in the formation of PEEK. These are

- "Electrophilic reaction"- this involves protonation of carbonyl group with different forms of fluoride.
- "Nucleophilic Displacement Reaction"- in this process, benzophenone or diaphenylsulfone are used for providing thermal stability to the resulting polymer [16].

Properties of PEEK

- It is a rigid material which have thermal stability up to 335.8°C.
- Its young' modulus is within the range of 10–30 GPa which is similar to human bone and dental tissues such as enamel and dentin [17].
- The value of flexural modulus, density and thermal conductivity are 140-170 MPa, – 1300 kg/m3 and 0.29 W/mK respectively [7].
- Katzer., et al. [18]. in 2002 have claimed that PEEK does not have any evidence of cytotoxicity or immunogenicity. They also concluded that PEEK is highly biocompatible in nature.
- In addition it also have resistance to low pH and wear which makes it more superior among others [19].

- Apart from these properties, it also have lowest solubility and water absorption when compared to PMMA and composite resin [18].

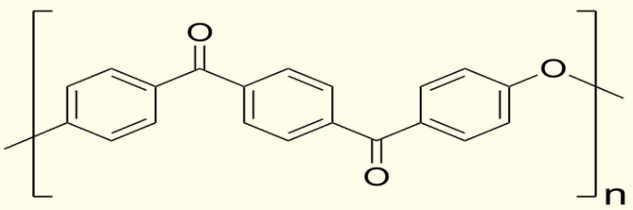

Figure 4: Structure of PEKK. (Source- Kewekordes, Wille, and Kern, 2018).

Instead of all these excellent properties, there is still doubt associated with the long-term success of PEEK. In order to resolve this issue, various modifications have been tried with the help of surface coatings, physical and chemical treatment. All these surface treatments has helped in increasing its osteoconductive properties [20]. The hydroapatite is one of the most commonly used material for surface treatment.

Physical treatment comprises of surface treatment with plasma modifications and accelerated neutral atom beam. Similarly, in chemical treatment different chemical reactions with titanium, gold, diamond like carbons along with sulfonation.

Apart from the bioactivity, in homogenous state, PEEK has weak properties. In a study by Tannous., *et al.* [21]. in 2012 concluded that PEEK clasps have shown lower resistance to occlusal forces as compared to conventional cobalt chromium ones. In addition, polymer bases frameworks are still limited for RPD designs such as occlusal rest and other retentive parts. Due to these drawbacks, a newer hpp is discovered which is called as BioPP. It mainly comprises of a modification of PEEK with 20% ceramic fillers. This material have superior aesthetic properties which makes it potential to use as framework. It also offers other properties like good stability, high polish ability and freedom of correction. It also have low plaque retention and higher resistance [22].

Polyetherketone ketone (PEKK)

PEKK is a new biomaterial which is free of methacrylate and is thermoplastic in nature. It is a high performance polymer which was invented back in 1962 by Bonner [23].

It is a linear aromatic polyether ketone which is generally represented by polyethylene (a high molecular weight substance). It consists of benzene ring which is attached with ether and ketone groups consecutively. Its source of production is from diphenyl ether with Aluminium chloride and nitrobenzene with iso and terephthaloyl chloride.

Like PEEK, it also comprises of aromatic rings which have variable ratio of ether and ketone group. In contrast to PEEK, PEKK has an additional ketone group which enhances its polarity and rigidity of backbone. This ultimately leads to changes in glass transition and melting point of the material [24]. A distinctive property which is present in PEKK is that it can present both amorphous and crystalline behaviour. Its melting temperature is 305°C whereas it is 360°C for PEEK.

Properties

It has excellent physical and mechanical properties. Unlike PEEK, its shows better flexural, compressive and tensile strength. On treatment with titanium dioxide, it shows improved wear resistance and hardness. It also has better shock absorbance and fracture resistance. Moreover, the value of modulus of elasticity of PEKK is same as that of dentin and also, its modulus of elasticity is similar to that of the human bone. It also has a comparable range of fatique in relation to chromium cobalt and polymethymethacrylate [25]. On the basis of Burke's classification, its fracture code lies between 1 and 2 which is same as that of zirconia [26]. All these properties makes it capable to be used as a restorative material [25].

In addition to all these mechanical properties, it has excellent biocompatibility. It has also been certified by FDA for oral and maxillofacial as well spinal surgeries [27]. In 2015, Schwitalla., *et al*. [28]. has concluded in their study that PEKK can be used as an alternative in patients who are unknown allergies. PEKK has additional ketone group which offers it with -SO3H. This helps in providing it complex surface topography with more surface area and micro rough surface.

When PEKK is used for removable partial framework, it shows favourable stress distribution. Such clasps provide longer duration of retentive features. It can also be used as inserts in RPDs. A study was carried out by Choi., *et al*. [29]. in 2018 on attachment systems using a PEKK insert. They found that there was significant difference in abrasion and retention change between PEKK and nylon. PEKK has shown less rate as compared to nylon.

Although PEKK has superior properties but still there are no enough evidence supporting its use and illustrating its limitations. Hence, long term studies on its properties are still required to achieve a more promising restorative material.

Aryl Ketone Polymers (AKP)

This is also a high performance polymer which is made by Solvay Dental 3360 and marketed under label of Ultaire AKP. It is a newer hpp which is being used in dentistry. Martin., *et al.* [31], in 2021 concluded in their study that Ultaire AKP has high flexural strength and impact. They also found that it has very negligible rate of water sorption and is resistant to surface roughness induced by

Properties	PEEK	PEKK	Titanium	PMMA
Tensile strength (MPa)	100.69	115	240-890	48-62 Mpa
Elastic modulus (GPa)	3.5	5.1	103-114	3.8×10^3
Flexural strength (MPa)	163.88	200	65	107-117
Compressive Strength (MPa)	118-169	246	130-170	76Mpa
Melting temperature (°C)	334-350	363-386	1650-1670	160
Hardness	26-29VHN	252MPa	90VHN	89-95MPa
Water absorption ($\mu g/mm^3$)	0.1-0.5	8.7	0.04	0.1-0.3
Density (g/cm^3)	13	FEFF1.3	4.4-4.5	1.16-1.18 g/cc

Table 2: Mechanical properties of PEEK and PEKK. (Source- Alqurashi, *et al*,2021).

cleaner. In the same study, authors also stated that clasps made up from Ultaire AKP have shown more elastic behaviour than those made up of cobalt chromium. Quiet similar results were found in one more study which was conducted by Marie., *et al.* [32].in 2019. They found that a consistent amount of retentive forces were experienced by Ultaire clasps with minimal deformation. Similarly when AKP, PEKK and cobalt chromium clasps were tested under occlusal forces for deformation, AKP and PEKK clasps have demonstrated low retentive features as compared to the cobalt chromium clasps [33].

Studies state that cobalt chromium have more tendency of Candida *albicans* and Streptococcus *mutans* growth. On comparison of biofilm formation with cobalt chromium, Ultaire has shown significantly less amount of micro-organisms. Hence, it can be an excellent material of choice for rpd framework as it has enhanced mechanical properties with low rate of bacterial proliferation[30].

Conclusion and Future Prospective

It can be undoubtedly claimed that high performance polymers have excellent properties which make them an attractive enough to be used in removable partial dentures fabrication. But one should not solely depend on the material of fabrication. There are several other areas like techniques, material and methods of fabrication which might need to be examined. In addition to these, the fundamentals of RPD design might need to be reframed again as those are based on the conventional methods of casting which are slowly being transformed to digital and non-invasion ones. Considerably more work will need to be done to find a more stable, sustainable, functional and biocompatible material.

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