PEEK polymer in orthodontics: a scoping review

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Abstract

Aim The aim of this scoping review was to evaluate the application of polyether-ether-ketone (PEEK) in orthodontics.

Methods Search strategies were executed for electronic databases through PubMed, Scopus, Web of Science, Lilacs, Opengrey, Embase, Cochrane Library and records identified through hand or electronic search. The keywords used were: "PEEK" OR "Polyether-ether-ketone" AND "orthodontics". The period selected of article publication was from January 2015 to June 2021.

Results Sixty-nine articles were found. After removing duplicates, 35 papers were analysed and only 11 full text were assessed for eligibility. Nine studies were included in its qualitative synthesis.

Conclusions Due to excellent physical, mechanical, aesthetic properties and biocompatibility, its low plaque affinity and flexural modulus close to enamel and dentin, PEEK can be used also in orthodontics. However, more clinical research should be done to find out all the advantages and disadvantages of this material.

KEYWORDS Polyether-ether-ketone; Digital orthodontics; Technopolymers.

Introduction

Digital technologies and new materials are becoming popular, getting better and changing diagnostic and treatment modalities in orthodontics [Ierardo et al., 2017]. Today it is possible to design a complete digital workflow for diagnosis and therapy [Beretta et al., 2021a]. The use of "self driving", or automatic, orthodontic devices, considering the average collaboration of paediatric patients, have led us to explore the innovative field of polymeric materials [Beretta and Cirulli, 2017]. The introduction in digital orthodontics of new materials such as technopolymers is offering new possibilities to the clinician [Ierardo, 2017; Beretta and Cirulli, 2017].

The research is studying the possibility of using metal-free appliances in orthodontics for many reasons, being allergy to metals and the interference of metals with magnetic resonance imaging two of the most common ones [Maekawa et al., 2015]. The term CAD/CAT (Computed Aided Design-Computer Aided Technofacturing) must permanently replace the no longer current CAD/CAM, because nowadays actual manufacturing is obsolete [Beretta and Cirulli, 2017]. In particular, Polyether-ether-ketone (PEEK), which is traditionally milled, has ideal chemical and physical features that warrant its use in orthodontics. Due to its biocompatibility, low plaque affinity and dimensional stability it can be used to produce orthodontic devices. PEEK is a polyaromatic semi-crystalline thermoplastic polymer originally introduced by victrex PLC in the early 1980s (at the time called ICI, Imperial Chemical Industries) for engineering applications. It was first commercialised for industrial applications in aircrafts, turbine blades, piston parts, cable insulation, bearings and compressor plate valves production [Ierardo et al., 2017]. PEEK is a colorless organic thermoplastic polymer and belongs to the PAEK (polyaryletherketone) family. It is a homopolymer having a single monomer. It is a semi-crystalline thermoplastic polymer with exceptional chemical and mechanical properties that are retained even at higher temperatures. Chemical composition and structure (branching of polymer) of PEEK make it stable at high temperatures, thus making the processing of PEEK implant components easy [Benakatti et al., 2019]. PEEK is resistant to deterioration when submitted to heat sterilisation procedures [Benakatti et al., 2019]. Its chemical structure makes it highly resistant to chemical and radiation damage, as well as compatible with reinforcing agents, such as glass and carbon fibers, with a higher resistance than metals. These properties make it highly suitable for industrial applications [Benakatti et al., 2019]. PEEK is widely used not only in engineering but also in medical applications because of its excellent thermal properties, superior wear resistance, great processability, inertness, corrosion resistance, high strength and modulus of elasticity. In fact, its elastic modulus is similar to that of human bone, suggesting homogeneous stress distribution to the surrounding tissues. Radiographic radiolucency and low density (1.32 g/cm^3) make it suitable for medical applications. Radiopacifiers like barium sulfate can be added to improve visualisation and contrast in medical imaging [Benakatti et al., 2019]. PEEK is an inert material highly compatible with the surrounding tissues and does not exhibit any toxic or mutagenic effects. Therefore, it can be an ideal substitute for patients allergic to titanium and other metals. PEEK does not have a metallic color; it appears beige with a touch of grey and has a more aesthetic appearance [Benakatti et al., 2019].

The aim of this review was to evaluate PEEK polymer and its use in orthodontics.

Material and methods

Literature search

A review of the literature was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. The literature search covered the following databases: Medline via PubMed, Scopus, Web of Science, Lilacs, Opengrey, Embase, Cochrane Library and records identified through hand or electronic search. The keywords used were: "PEEK" OR "Polyether-ether-ketone"

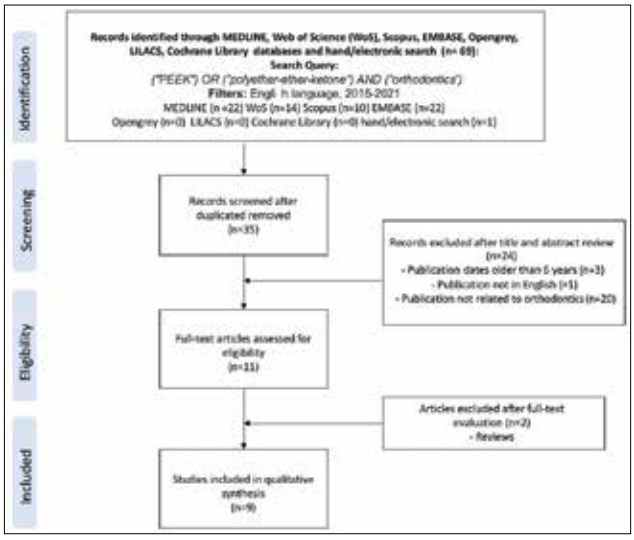

FIG. 1 Article selection process (PRISMA 2015 checklist).

AND "orthodontics". The period selected was from January 2015 to June 2021. After a first screening based on study title and abstract, all papers were assessed based on full text and excluded with reasons when appropriate.

Two reviewers (M.P. and S.C.) carried out this process independently. Disagreement was solved by a third party (L.P.).

Eligibility criteria

Given the novelty of PEEK materials, also case reports and case series were included for qualitative analysis. Conversely, retrospective studies, low-quality prospective studies, review articles, editorials, comments and meeting abstracts were excluded.

Data extraction

The titles and abstracts of all references retrieved in the searches were screened for potential eligibility, and the full texts of articles identified as possibly being relevant were obtained and evaluated. After full text evaluation, data were independently extracted by two authors (M.P. and S.C.) for further assessment of qualitative analyses. A flowchart for the article selection process according to PRISMA 2015 checklist is detailed in Figure 1.

Results

Sixty articles were found in the database using keywords: "PEEK" OR "polyether-ether-ketone" AND "orthodontics".

Medline search yielded 22 publications; Embase, 22 publications; Web of Science, 14 publications; Scopus, 10 publications; Cochrane Library, LILACS and Opengrey 0 publications. In addition, one (1) record was identified through electronic search. Studies over 6 years old were not included, as well as publications not in English. After removing duplicates, 35 papers were analysed and only 11 full texts were assessed for eligibility. Two articles were excluded because they are revisions. Nine studies were included in the qualitative synthesis.

Discussion

Due to excellent physical, mechanical, aesthetic properties and biocompatibility, PEEK can be used in many fields in dentistry.

The literature research focused mainly on implants and fixed or removable prosthesis. Indeed, using the keywords "PEEK" OR "Polyether-ether-ketone" AND "orthodontics" results were very few, while searching "PEEK" OR "Polyether-ether-ketone" AND "dentistry", multiple results appeared. For example, in the Cochrane Library database, no Cochrane Reviews were present in title, abstract and keyword typing "polyether ether ketone" AND "orthodontics" (Issue 5 of 12, May 2021), while typing "polyether ether ketone" AND "dentistry", seven trials concerning dental prostheses appeared.

This scoping review aims at highlighting another aspect of the use of PEEK in orthodontics. The studies included in the analysis showed that PEEK can be used as a space maintainer [Ierardo et al., 2017], orthodontic wire [Tada et al., 2017; Shirakawa et al., 2018; Maekawa et al., 2015], zero-expander appliance [Beretta et al., 2021a], orthodontic appliance [Aretxabaleta et al., 2021] and post-orthodontic treatment retainer [Kadhum et al., 2020; Beretta et al., 2021b]. The different clinical application makes PEEK appliance comparison difficult.

The common characteristics found in the articles are breaking strength, aesthetics, resistance to sterilisation, safety and comfort. Thanks to its properties, PEEK can be used as passive or active device. Regarding its passive action, Ierardo [2017] made three prototypes of orthodontic devices: lingual arch, band with loop and removable plate. The purpose of the devices was space maintainance during the transition from deciduous to permanent teeth either in patients with deciduous decayed teeth or in patients subjected to extractions for orthodontic purpose. Also Kadhum and Alhuwaizi [2020] studied PEEK as a retainer showing that 0.8 mm round PEEK wires have comparable performances, in terms of debonding and pull-out forces, to conventional retainers when bonded with 4 mm composite bonding spot. Another benefit of PEEK is its radiolucency, which is very useful when a panoramic radiogram is required during treatment, since the absence of metal reduces the possibility of artifacts [Beretta et al., 2021a].

As regards to active performances, PEEK was used as orthodontic wire [Tada et al, 2017; Maekawa, 2015] showing promising features in load deflection curve, bending force, permanent deformation, static friction and creep resistance. Further studies are needed to evaluate the effective superiority of PEEK over NiTi. Beretta et al. [2021a] used PEEK with the ZeroExpander which, due to its shape memory, progressively expands like a compressed open coil spring (a sort of preactivated Quad-Helix), until it reaches the original dimension at the end of a virtually planned expansion, in a very controlled and comfortable way for young patients. Notably, the author pointed out that the use of new digital technologies has enormously changed the workflow in orthodontics, allowing the clinician to work using fully digital protocols. The workflow is constantly changing, moving from devices made in CAD (Computer-Aided Design)/CAM (Computer-Aided Manufacturing) to devices made in CAD/CAT (Computer-Aided Technofacturing). To date, speaking of "manufacturing" is no longer appropriate as the designing phase takes place using a CAD software while the subsequent processing takes place using milling machines and 3D printers; therefore the new acronym CAD/CAT should be used to underscore the concept of technofactoring [Beretta et al., 2021b].

Beside PEEK, the polymer "polyamide 12 -PA12"could be particularly interesting. It is a biocompatible, semi-crystalline, linear, 3D-printable thermoplastic composite material. It is thermally stable up to 185 ° C, so it can be sterilised before clinical use, due to its greater flexural strength and modulus.

Authors	Public. year	Device	Properties
Beretta M, Mangano A, Gianolio A, Federici Canova F, Negrini S, Cirulli N.	2021	Fixed retainer following orthodontic treatment in PEEK	Biocompatibility - Hydrolysis resistance Low plaque affinity - Flexural modulus close to enamel and dentin - Perfect fit
Aretxabaleta M, Xepapadeas AB, Poets CF, Koos B, Spintzyk S (Fracture load of an orthodontic appliance for robin sequence treatment in a digital workflow. Aretxabaleta M, Xepapadeas AB, Poets CF, Koos B, Spintzyk S.Materials, PubMed)	2021	Tübingen palatal plate (TPP) in PEEK	Ductile behavior - High safety margin - High fracture load - Safe material - Expensive
Aretxabaleta M, Xepapadeasa AB, Poets CF, Bernd K, Spintzyk S (Comparison of additive and subtractive CAD/CAM materials for their potential use as Tübingen Palatal Plate: An in-vitro study on flexural strength (WoS))	2021	Tübingen palatal plate (TPP) in PEEK	The results indicate that almost all tested CAD/CAM materials had superior mechanical properties compared to the conventional cold polymerising PMMA Orthocryl
Kadhum AS, Alhuwaizi AF.	2020	Wire as a retainer following orthodontic treatment in PEEK	The 0.8 mm round wire-form has comparable performance (in terms of debonding and pull-out forces) to conventional retainers when bonded with 4 mm composite bonding spots
Beretta M, Federici Canova F, Gianolio A, Mangano A, Paglia M, Colombo S, Cirulli N	2020	Zero expander in peek and zero expander in PA12	Both effective and comfortable Radiolucent
Shirakawa N, Iwata T, Miyake S, Otuka T, Koizumi S, Kawata T	2018	Orthodontic wires covered with a polyether ether ketone tube	Sufficient aesthetic property The frictional force was greatly reduced by passing the archwire through the PEEK tube
Ierardo G, Luzzi V, Lesti M, Vozza I, Brugnoletti O, Polimeni A, Bossù M	2017	Space maintainers in peek polymer	Comfortable, satisfying, personalised and minimally visible - Suitable for space maintainers Dimensional stability, mechanical strength and biocompatibility
Tada Y, Hayakawa T, Nakamura Y	2017	PEEK wires: -rectangular 0.016x 0.022 0.019x0.025 -round 0.016 -control 0.016 NiTi	Load deflection curve similar to control except 0.016 PEEK Comparable bending force No significant difference in permanent deformation No significant difference in static friction
Maekawa M, Kanno Z, Wada T, Hongo T, Doi H, Hanawa T, Ono T, Uo M	2015	Orthodontic wires	Excellent aesthetics - Bending strength Creep resistance - Quite low water absorption

TABLE 1 The works included in the qualitative synthesis.

Conclusion

With the help of 3D-printing technology, there is no restriction of design iterations ("rapid prototyping") during product development and manufacturing as compared to other conventional manufacturing technologies.

Unfortunately, the clinical research published so far is not sufficient to prove the superiority of PEEK over other materials. There is still not enough information about retention, load-deflection, static friction or biofilm formation on PEEK surface and its resistance to compression. More clinical research is needed to evaluate these aspects.

Modern orthodontics shows an increased demand for metal-free, customised and fully digital workflow materials for the fabrication of appliances, which represent the right steps towards the future of tailor-made orthodontics.

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