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POLYETHERETHERKETONE IN DENTAL IMPLANTS. A REVIEW.

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Abstract.

Polyetheretherketone (PEEK) is a polymer that has been used for several decades in engineering, but later entered the medical field. Being a biocompatible material and because it has shown resistance to in vivo degradation, it was launched in 1998 as a biomaterial for implants intended for long-term use. PEEK has demonstrated that it is a high performance thermoplastic polymer, capable of replacing implant metal components, initially in the field of orthopedics. These findings suggested that PEEK could also replace titanium for dental implants. PEEK applications in dentistry are diverse, from crowns, bridges and removable dental prostheses to dental implants. The material comes in the form of discs that will be milled using CAD-CAM technology, but can be processed by various techniques, including injection molding, and extrusion. The manufacturers claim that these devices have very good mechanical properties, easier work with than ceramics and titanium, and can be applied to patients with allergies.

Key words: Polyetheretherketone (PEEK), Dental Implants, Carbon Fiber Reinforced PEEK

The science of biomaterials has registered a significant evolution in the last decades, new materials being manufactured and offered to the medical field for their use as devices with a high rate of predictability of clinical success. In recent decades, dental implants have gained great popularity among patients, dominating the other treatment options and being often considered as the first therapeutic option Forna 1. The first attempts to use methyl methacrylate in implants were unsuccessful. [**2, 3]**, but in 1969, researches on polymethacrylate implants led to the development of the concept of polymer dental implant by Milton Hodosh, who reported polymers as biologically tolerable substances. According to Hodosh, the main reasons for trying to use polymers for implants are: their physical characteristics may be altered by changing their chemical composition; can be easily handle and allow very good reproduction; does not generate galvanic currents as metals do; attaches to the fibrous connective tissue; are more aesthetic than metals; are thermal and electrical insulators and are relatively resistant to biodegradation **[4]**.

The main polymer's disadvantages are: poor mechanical resistance, lower Young's Modulus than the bone, lack of adhesion to tissues, immune side effects. In general, polymers are sensitive to sterilization and handling techniques. If their intended use is for implants, most cannot be sterilized with steam or ethylene oxide. Some polymeric biomaterials tend to collect dust or other particles due to their electrostatic surface properties and [**5**]

The main categories of polymers used to make dental implants are: Polymethylmethacrylate (PMMA), Polytetrafluoroethylene, Polyethylene, Polyamides, Polysulfones, Polyurethanes, Polyetheretherketone (PEEK).

Polyetheretherketone (PEEK) is a polymer that has been already used for several decades in engineering, but later entered the medical field. Being a biocompatible material and showing good resistance to in vivo degradation, it was proposed in 1998 as a biomaterial for implants. Since then, PEEK has demonstrated that it is a high performance thermoplastic polymer, capable of replacing implant metal components, initially in the field of orthopedics **[6]**.These findings suggested that PEEK could also replace titanium for dental implants.

PEEK applications in dentistry are diverse, from crowns, bridges and removable dental prostheses to dental implants launched over the past 10 years. The manufacturers (NT-Trading, Invibio, etc) claim that these dental prostheses have very good mechanical properties, easier work with than ceramics and titanium, and can be indicated in patients with allergies. The material comes in the form of discs suitable for CAD-CAM technology, but can be also processed by various techniques, including injection molding, and extrusion.

The PEEK advantages are:

- the bone-like Young's Modulus helps to reduce tension and stimulate bone healing
- withstands multiple cycles of steam sterilization (up to 134° C), ethylene oxide, plasma without changing its mechanical properties or biocompatibility
- suitable for devices that will be implanted in contact with bone, blood or other tissues for more than 30 days
- excellent mechanical properties: rigidity, toughness, durability, creep resistance, compression resistance, traction and fatigue resistance,. Meets all biofunctional standards for dental implants (EN ISO 14801). PEEK implants do not break or crack even after 5,000,000 operating cycles [**7, 8**].
- high chemical resistance, does not produce corrosion
- natural color that allows to obtain excellent results from an aesthetic point of view, the implants not being visible through the peri-implant mucosa
- proven biocompatibility for hard and soft tissues **[9]**
- allows the dentist to make changes in the office
- flexibility close to the maxillary bone, therefore the deformation will be similar to it
- stimulates the remodeling of the peri-implant bone, so it is osteoconductive, the observed bone response is similar to that of a graft
- immediate loading is possible
- does not produce heating by screwing
- does not interfere with radiological methods of Rx, CT, MRI imaging **[7, 8]**
- radiolucency allows easier monitoring of the healing process

Unlike very rigid Titan implants (modulus of elasticity 110 GPa), PEEK implants have a modulus of elasticity of 3.6 GPa, which is closer to that of bone (≈1–30 GPa) [**10**]. This parameter can be modified (sometimes even much increased) by reinforcing the polymer with carbon fibers, for example, to obtain a modulus of 18 GPa, similar to that of cortical bone [**11]**.

PEEK implants are metal-free solutions, indicated for patients with metal intolerance or those who want metal-free therapeutic solutions. PEEK has demonstrated an excellent ratio of strength to weight (it is very light compared to metals), offering a high degree of protection against stress that can be beneficial to the level of bone around the dental implant.

CARBON FIBER REINFORCED PEEK (CFR PEEK) is a composite material composed of layers of carbon fibers with different orientations, in a polymeric PEEK matrix. The mechanical properties of CRF PEEK are determined by the volume, length and alignment of the fibers.

For medical applications two types of carbon fiber incorporations are used: short and long. The short CRF PEEK consists in the random placement of carbon fibers shorter than 0.4 mm, obtaining a homogeneous isotropic material. CFR PEEK long contains fibers that cross the entire width of the implant, which leads to a tensile strength of over 200 MPa, compared to 170 MPa for short CRF-PEEK. Controlled alignment of carbon fibers can provide a wide range of anisotropic properties, which can be adapted for a specific application [6]. Depending on the orientation of the fibers, the modulus of elasticity may increase to values of 150 Gpa, as is the case with fibers arranged in parallel (Endolign® implant)

This material has more biomechanical advantages compared to traditionally used metals such as titanium or stainless steel. The high fatigue resistance and low elasticity make CFR-PEEK an ideal material for orthopedic implants [7]. CRF PEEK implants can be designed to have different degrees of strength and rigidity, based on the number of layers of carbon fiber and their orientation. This can allow the manufacture of an implant that is more suitable than the metal, which better corresponds to the modulus of elasticity of the bone.

The modulus of elasticity of PEEK is 3.5 GPa, compared to 230 GPa for stainless steel, 210 GPa for chromium cobalt, 106-155 GPa for titanium alloys, 12-20 GPa for cortical bone and 1 GPa for spongy bone [12]. The plates and screws made of this material available on the market were tested for fatigue and withstood 1 million cycles without fail. The average value of the bending strength of a 4.5 mm CFR-PEEK plate is 19.1 Nm, while that of a similar stainless steel plate is 16.7 Nm. The average value of the bending strength of a 10 mm CFR-PEEK screw is 80.3 Nm, while that of an 11 mm titanium screw is 43 Nm [13]. The radiological compatibility and magnetic resonance (MRI) of CFR-PEEK are two more additional features that make this material beneficial, due to the lack of artifacts on both computed tomography (CT) and MRI [14].

In an FEA study, the biomechanical behavior of three dental implants was compared: one of CFR PEEK (Endolign®), one of powder-reinforced PEEK and one of Titanium as a control. A 100N force was applied, both vertically and at an angle of 30° to the axis of the implant. All types showed a minimal safety factor in terms of cortical bone strength. Within the limits of that study, the powder-reinforced PEEK implant produced the highest tensions in the adjacent cortical bone compared to titanium and CFR-PEEK. Long carbon fibers give PEEK high stability. Further research is needed to assess whether there is a distinct amount of carbon fiber that determines an optimal stress distribution behavior in the case of CFR-PEEK [15, 16].

Although there are advantages in using CFR-PEEK, there are also specific disadvantages. Although low stiffness can be beneficial, too much flexibility can be disadvantageous, potentially leading to pseudoarthrosis. In addition, being radiolucent, it makes it very difficult to visualize the implant on radiography, requiring the addition of radiopaque markers to help visualize it.

There are currently a relatively small number of studies in the literature have compared PEEK (or PEEK-based) implants with titanium implants, so that their feasibility as a possible substitute for titanium can be determined.

However, the bioactivity and osseointegration of PEEK are intensely discussed. The question is: "Are the bioactivity and osseointegration of PEEK implants comparable or better than that of titanium implants?" In 4 of 5 in vitro studies, titanium showed higher cell proliferation, angiogenesis, osteoblast maturation and osteogenesis compared to PEEK. An in vitro study observed comparable results regardless of the implant material. In all animal studies, uncoated and coated titanium showed more osteogenic behavior than uncoated PEEK, while the implant / bone contact observed with hydroxyapatite (HA) coated PEEK and coated titanium implants was comparable. Unmodified PEEK is less osteoconductive and bioactive than titanium. Therefore, in its unmodified form, PEEK is not suitable for use as a dental implant. Long-term research and studies should focus on improving PEEK bioactivity before it is used as a dental implant. More comparative animal studies and clinical trials are needed to determine the potential of PEEK as a viable alternative to titanium [17]

The literature currently contains a very small number of studies reporting PEEK as an alternative material for dental implants.

One experiment performed on dogs compared CFR-PEEK with titanium-coated CFR-PEEK implants, inserted in the femur and evaluated after 4 and 8 weeks, respectively. Titanium-coated implants showed a significantly higher rate of implant / bone contact (BIC), the authors concluding that the addition of the titanium layer apparently increases the biocompatibility of the implant surface. Using the BIC rate as a parameter for the degree of osseointegration, it can be stated that both CFR-PEEK implants (covered and uncovered) have the desired osseointegration compared to the BIC values of titanium implants. In a second study in dogs, pure PEEK implants were inserted into the mandibles next to titanium, zirconia, and coated zirconia implants to evaluate osseointegration. After 4 months, PEEK implants have the lowest BIC. No signs of inflammation or foreign body reactions were observed in either of the two animal investigations, which underscores the biocompatibility of PEEK [18, 19].

An in vitro experiment studied the possibility of attaching a collagen gel to the surface of PEEK by enzyme induced mineral deposition. If this type of coating could be used to anchor a PEEK implant in the alveolar bone with collagen fibers as a natural tooth, it could be another advantage of PEEK over titanium, giving back to the bone the physiological load of traction to the bone [20].

An FEM study compared the distribution of stress in the peri-implant bone in a titanium implant or CFR-PEEK, containing 30% carbon fibers to obtain a modulus of elasticity of 17.4 GPa similar to that of cortical bone. CFR-PEEK implants showed a higher concentration of stress in the cervical area and cortical bone than titanium implants, while titanium implants showed equivalent stress peaks in the cervical portion and a more homogeneous distribution of the load throughout the body implant. The authors acknowledge that the higher stress concentrations of the PEEK implant were not expected. A more homogeneous distribution of stress was meant to decrease the stress peaks at the implant-bone interface. Therefore, they concluded that the CFR-PEEK implant demonstrates higher stress peaks due to its reduced rigidity compared to titanium, has no advantages compared to the titanium implant and cannot be recommended for clinical use. This rate of deformation could be diminished by an internal stiffening of the implant, while the biomechanical behavior of a PEEK implant must be tested experimentally to obtain accurate data. [21].

Existing data on PEEK dental implants demonstrate that PEEK is, in principle, osseointegrated as a biocompatible material in vivo. Further investigation is needed to improve biomechanical behavior to obtain a more homogeneous distribution of stress to the surrounding bone, which has not yet been proven experimentally. Long-term investigations into in vitro and in vivo loaded PEEK implants are needed. Experimental surface modulations are also required to obta1in the highest degree of osseointegration. PEEK used for a dental implant must have a slight translucency similar to a natural tooth to obtain favorable aesthetic results. Existing articles on PEEK dental implants indicate that PEEK could be a viable alternative material for dental implants. However, new experimental studies on the chemical modulation of PEEK seem to be needed, mainly to increase the BIC rate and minimize the stress distribution to the perimplant bone [15].

CRF PEEK (PEEK carbon fiber reinforced) has demonstrated excellent biocompatibility, causing a minimal cellular response when studied in vitro and in vivo [9, 22], but the number of studies available at this time is extremely small, totally insufficient to formulate relevant conclusions, and new future studies are needed to confirm these views.

PEKK (POLY ETHER KETONE KETONE) is the newest member of the PAEK family (Poly-Aryl-Ether-Ketone) launched by Cendre Metaux (Switzerland), as a material for metal replacement in dental implants. PAEK are high-performance thermoplastic polymers that, thanks to a wide range of temperatures, have high strength, rigidity and resistance to hydrolysis, thus being usable in extremely demanding conditions. Their crucial advantage is that when processed by temperature, only the shape changes, not the chemical properties. Another advantage is the lack of porosity or monomers.

PEKK has become in recent years synonymous with top performance in the field of polymers, gaining wide acceptance in medicine and several other specialties [23]. It seems to demonstrate a number of advantages for use in dentistry, because, unlike PEEK, it has both amorphous and crystalline properties. The chemical structure of PEKK guarantees the best mechanical properties in the whole Poly-Aryl-Ether-Ketone family. It has up to 80% higher compressive strength than PEEK, and acts as a shock absorber, due to its compression abilities, acting similar to natural teeth, being an excellent choice for patients with bruxism. Due to its unique mechanical, physical and chemical properties, it is suitable for a wider range of uses than PEEK.

The color is not very similar to that of the tooth, but more like that of the bone. To remove the aesthetic disadvantage, the Pekkton® ivory material was launched, which has another extra ketone in the chemical structure, modifying the ketone / ether ratio, which gives it other advantages: superior mechanical and physical properties; can be polished better, easier and faster; the surface is more attractive and compact, thus reducing the risk of bacterial colonization. As the structure of the polymers is different, the processing behavior will be different, leading to different results in terms of strength, stiffness, melting point and melting behavior.

As in the case of PEEK, PEKK material can be processed by different technologies, from the classic lost wax, to CAD-CAM milling.

CONCLUSIONS

The characterization of the surface condition and the understanding of the mechanism by which this parameter, together with the material properties influences the osseointegration as well as the biocompatibility of dental implants, represent one of the most important aspects in implantology. As important as the biomaterial and design of the implant is the type of bone in which it will be placed. Given the wide variety of biomaterials and the multitude of implants on the market at the moment, it is mandatory a very good knowledge of the characteristics and the indications of each type of implant.

Based on the data currently available in the literature the following conclusions can be drawn: PEEK implants have been suggested as an alternative to replace titanium in the manufacture of dental implants but the literature currently contains a very small number of studies to recommend them with certainty. In the few investigations on animals, no signs of inflammation or reactions of the foreign body were observed, which emphasizes the biocompatibility of this material, instead it has the lowest BIC compared to zirconia and titanium. Unmodified PEEK is less osteoconductive and bioactive than titanium. Therefore, in its unmodified form, does not appear to be suitable for use as a dental implant. Long-term research and studies should focus on improving the bioactivity of PEEK before it can be used as a dental implant. Several comparative animal studies and clinical trials are needed to determine the potential of PEEK as a viable alternative to titanium. Regarding CFR-PEEK implants, they showed a significantly higher implant / bone contact rate, higher stress peaks due to its reduced rigidity compared to titanium, has no advantages compared to the titanium implant and cannot be recommended for clinical use.

Further investigation is needed to find ways to improve biomechanical behavior to obtain a more homogeneous distribution of stress to the surrounding bone, which has not yet been proven experimentally. Experimental surface modulations are also required to obtain the highest degree of osseointegration.

REFERENCES

1. Forna NC. Statistic study regarding the ards using implants accord with clinical cases particularities

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2. Ashman A. Acrylic resin tooth implant: a progress report. J Prosthet Dent 1971; 25: 342-347
3. Gettleman L, Nathanson D, Myerson RL. Effect of rapid curing procedures on polymer implant materials. J Prosthet Dent 1977; 37: 74-82 [
4. Hodosh M, Povar M, Shklar G. The dental polymer implant concept. J Prosthet Dent 1969; 22: 371-380
5. Shtilman M.I. Polymeric Biomaterials: PART 1, Taylor & Francis, 2003, ISBN 9067643890
6. Kurtz SM, Devine JN. PEEK biomaterials in trauma, orthopedic, and spinal implants. Biomaterials. 2007;28:4845–4869.
7. Hak DJ, Mauffrey C, Seligson D, Lindeque B. Use of carbon-fiber-reinforced composite implants in orthopedic surgery. Orthopedics 2014 Dec;37(12):825-30
8. Rohner B, Wieling R, Magerl F, Schneider E, Steiner A. Performance of a composite flow moulded carbon fibre reinforced osteosynthesis plate. Vet Comp Orthop Traumatol. 2005;18(3):175-82.
9. Katzer A, Marquardt H, Westendorf J, Wening JV, von Foerster G. Polyetheretherketone: cytotoxicity and mutagenicity in vitro. Biomaterials.2002; 23(8):1749-1759.
10. Moon SM, Ingalhalikar A, Highsmith JM, Vaccaro AR. Biomechanical rigidity of an all-polyetheretherketone anterior thoracolumbar spinal reconstruction construct: an in vitro corpectomy model. Spine J. 2009;9:330–335.
11. Skinner HB. Composite technology for total hip arthroplasty. Clin Orthop Relat Res. 1988;235:224–236.
12. Golish SR, Mihalko WM. Principles of biomechanics and biomaterials in orthopaedic surgery. J Bone Joint Surg Am.2011; 93(2):207-212.
13. Steinberg EL, Rath E, Shlaifer A, Chechik O, Maman E, Salai M. Carbon fiber reinforced PEEK Optima: a composite material biomechanical properties and wear/debris characteristics of CF-PEEK composites for orthopedic trauma implants. J Mech Behav Biomed Mater.2013; 17:221-228.
14. Schulte M, Schultheiss M, Hartwig E, et al. Vertebral body replacement with abioglass-polyurethane composite in spine metastases: clinical, radiological and biomechanical results. Eur Spine J.2000; 9(5):437-444.
15. Schwitalla A., Müller W-D. PEEK Dental Implants: A Review of the Literature, Journal of Oral Implantology. 2013;39(6):743-749.
16. Schwitalla A., M. Abou-Emara, T.Spintig., J.Lackmann, W.D.Müller. Finite element analysis of the biomechanical effects of PEEK dental implants on the peri-implant bone Journal of Biomechanics, Volume 48, Issue 1, 2 January 2015, Pages 1-7
17. Shariq Najeeb, Zohaib Khurshid BDS, Sana Zohaib BDS and Muhammad Sohail Zafar BDS. (2016) Bioactivity and Osseointegration of PEEK Are Inferior to Those of Titanium: A Systematic Review. Journal of Oral Implantology 42:6, 512-516
18. Koch FP, Weng D, Krämer S, Biesterfeld S, Jahn-Eimermacher A, Wagner W. Osseointegration of one-piece zirconia implants compared with a titanium implant of identical design: a histomorphometric study in the dog. Clin Oral Implants Res. 2010;21:350–356.
19. Cook SD, Rust-Dawicki AM. Preliminary evaluation of titanium-coated PEEK dental implants. J Oral Implantol. 1995;21:176–181.
20. Berendsen AD, Smit TH, Hoeben KA, Walboomers XF, Bronckers AL, Everts V. Alkaline phosphatase-induced mineral deposition to anchor collagen fibrils to a solid surface. Biomaterials. 2007;28:3530–3536.
21. Sarot JR, Contar CM, Cruz AC, de Souza Magini R. Evaluation of the stress distribution in CFR-PEEK dental implants by the three-dimensional finite element method. J Mater Sci Mater Med. 2010;21:2079–2085.
22. Jockisch KA, Brown SA, Bauer TW, Merritt K. Biological response to chopped-carbon-fiber-reinforced PEEK. J Biomed Mater Res.1992; 26(2):133-146
23. Hatim Alqurashi, Zohaib Khurshid, Azeem Ul Yaqin Syed, Syed Rashid Habib, Dinesh Rokaya, Muhammad Sohail Zafar, Polyetherketoneketone (PEKK): An emerging biomaterial for oralimplants and dental prostheses Journal of Advanced Research, 2021Vol 28, Feb,:87-95