REVIEW

PEEK materials as an alternative to titanium in dental implants

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Abstract:

Titanium (Ti) and its alloys are widely used for dental implant treatment. The insertion of dental implants containing titanium can be associated with various complications. Advancements in dental materials have given dentistry more promising materials, yet each material remains short of being the ideal one. Polyether ether ketone (PEEK) is one of the viable materials which is scientifically approved and safe materials in medical and dental use. Due to its excellent properties PEEK has several applications in field of dentistry like implants, removable and fixed partial dentures, and orthodontic wires. The aim of this article is to evaluate whether PEEK can be used as an alternative material for dental implants.

Key words: Biocompatibility, implants, PEEK, surface modification, titanium

Introduction

The universal choice for implant material has been titanium and its alloys for decades. Its properties such as, strength, low weight, resistance to corrosion and biological inertness made it a wonder metal for dental implants.[1] Even so, the implants based on titanium and its alloys, such as Ti-6Al-7Nb and Ti-6Al-4V are not without problems. Studies have concluded that Titanium should no longer be considered biologically inert as it can induce clinically relevant hypersensitivity,[2] when chronically exposed in certain patients. Another problem is the peri implant bone loss due to stress between the bone implant interface during load transfer, which is due to the difference in the elastic moduli of the surrounding bone and the titanium implants.[3] Even though pure titanium and its alloys are resistant to corrosion due to the formation of a stable oxide layer, when this layer is removed, like other base metals it is also corrosive.[1] Also, titanium can cause aesthetic problems due to its lack of light transmission.3 Metallic dental implants when comes in the field of irradiation evokes scattering of rays which are harmful for tissues.[3] As the esthetic demands are increasing day by day, there is an increase in number of patients seeking dental rehabilitation with completely metal-free materials.[3] To overcome these limitations and enhance the properties, several researches has been carried out in order to design

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alternative substitutes to titanium. PEEK (Polyether ether ketone) is one of the promising novel materials,[1] which has superior esthetic and mechanical properties with different use in various specialities of dentistry.

History:

PEEK is a two-phase, semi-crystalline polymer with between 30 and 35% crystallinity and is a member of polycyclic aromatic polymer (-C6 H4 -OC6 H4 -O-C6 H4 - CO-)n which was developed in 1978 by Victrex PLC then ICI (imperial chemical industries) for engineering applications.[5] This material is obtained as a result of the binding of ketone and ether functional groups between aryl rings and is an element which is tan-coloured in its pure form.[6] By the late 1990s, Victrex PEEK business (Imperial Chemical Industry, London UK) launched PEEK-OPTIMA as an important high-performance thermoplastic candidate for replacing metal implant components.[7]

Applications:

The commercial process was started with the aim of industrial use, such as for turbine blades in the aircraft industry, since it is lighter than aluminium and the recyclability is better than aluminium. PEEK's mechanical properties over a wide temperature range make it useful in the manufacture of car components such as seals, washers and bearings. It is an excellent electrical insulator and retains its mechanical properties at high temperatures. It can thus find application in electrical instruments that operate at high temperatures, such as soldering machines. PEEK has potential in the food packing industry after approval from the US Food and Drug Administration. It is also replacing stainless steel in impeller wheels for regenerative pumps because it offers less noise and improved wear resistance. It is insoluble in most polymeric solvents and also does not undergo hydrolysis, even at high temperatures. This, coupled with PEEK's relative inertness to chemical reactions, means that it is perfect for biomedical applications such as in orthopaedic and trauma cases. Excellent results have started to be seen at a competitive level with the titanium material in particular, so this material can be used in dentistry as an alternative in implantology.[8]

Properties:

PEEK, is a white radiolucent rigid material which has a potential to serve as an aesthetic dental implant material. It has high thermal resistance up to 300°C, therefore, it can be processed with hot sterilization methods and is resistant to steam gamma and ethylene oxide sterilization methods.[5] PEEK also shows resistance to hydrolysis, and has superior mechanical properties.6 Studies have proved that, there is no evidence of cytotoxicity, mutagenicity, carcinogenicity, or immunogenicity.[6] It has a low plaque affinity and less chance of allergic reactions.[5] It is compatible with modern imaging technologies and allows magnetic resonance imaging. Studies show that radiation heat do not to cause any disintegration of the material.8 It has excellent chemical resistance and biomechanical properties.[7] Young's modulus of PEEK is around 3.6GPa. Meanwhile, Young's modulus of carbon-reinforced PEEK (CFR-PEEK) is around 18GPa which is close to that of cortical bone. So, the stress formed between the bone and the implant interface is less due to the absorption of forces and there is an advantage of bone protection unlike that of titanium where there are chances of bone resorption due to high elastic moduli.[9] PEEK has a high tensile strength which can be greatly improved when reinforced with carbon fibres, reaching a value of 29,000psi (200MPa). It is very light and has low density (1.32g/cm3).[8] PEEK also has very low water solubility and water absorption.[5] It is also highly resistant to creep. It can withstand reasonably high load for extended periods and at high temperatures without undergoing permanent deformation.[8]

Role in dentistry:

In removable prosthesis and its components

PEEK can be used to construct clasps and dentures by CAD CAM systems due to its superior mechanical properties. Also, the partial denture frameworks made of PEEK, provide good resiliency and superior patient comfort due to its light weight when compared to metal frame work. PEEK frameworks are shock absorbent during mastication, have an excellent resistance to decay and abrasion. Another major use is for making removable obturator. PEEK-OPTIMA (reinforced poly-ether-ether-ketone) has several features such as ease of polishing, machinability this allows the material to be used in the palatal section of maxillary obturator prostheses.[11] The use of PEEK simplified the fabrication of the antral section of the obturator and resulted in significantly lighter obturator prosthesis, with great improvement in the strength and the retention. Constructing obturator prosthesis with PEEK-OPTIMA is a good alternative to conventional materials and methods for patients with large oral-nasal defects.7

In fixed prosthesis

PEEK material can be used as a crown material because of their high wear resistance and because they do not deteriorate during processing. They also lend themselves to easier repair than ceramics.[6] As this material is lighter than metal ceramics this can be used as a suitable alternative to it. It does not corrode when in contact with other metals in the mouth, so can be used in patients who already have metallic restorations. As it is insoluble in water and has a low reactivity with other materials, it is a suitable alternative for patients with a metal allergy or who are sensitive to metallic taste. Despite the low elasticity modulus and hardness, the high resistance to wear makes this a material that can compete with metallic alloys. The resistance to breakage of PEEK fixed prostheses milled with CAD CAM is higher than that of lithium disilicate glass ceramic, aluminium, and zirconium unit PEEK prostheses produced with CAD-CAM have higher breakage resistance than granular-pressed or pellet-shaped PEEK prostheses.[12] In previous studies, it has been suggested that [3].

Bonding of PEEK to composites

It can bind to indirect composites polymerized with light. To meet aesthetic requirements, this material which shows low half-lucency can be coated with composite resins. Various adhesive systems are used to increase the bond between composite resins and PEEK.[6] Studies suggest that PEEK can be used under resin composite as a coping material. As the mechanical properties of PEEK are similar to those of dentin and enamel, PEEK could have an advantage over alloy and ceramic restorations. Taking into account the good abrasion resistance, mechanical attributes and the aforementioned adequate bonding of PEEK to composites and teeth[12], a PEEK fixed partial denture could be expected to have a satisfactory survival rate.[12]

In implantology

PEEK has exhibited high biocompatibility in dentistry. This material could be an alternative to conventional materials in implantology. Titanium and alloys are selected in implantology because of biocompatibility, resistance to corrosion and mechanical properties. Despite these advantages of titanium, there are some disadvantages such as bone resorption and subsequent implant failure, sensitivity reactions etc., which are causes of concern. These negative aspects that can be seen in titanium implants could be overcome with the use of an implant produced from a non-metallic material such as PEEK. One of the major reasons for any implant failure is the screw loosening followed by breakage, screws that made of PEEK can be retrieved more easily than the titanium screws. Because of the high mechanical properties, it has been advocated that this material can be used both as an abutment and prosthetic material in implantology.[6]

One of the limitations is that, although PEEK does stimulate the cellular proliferation, the cells proliferating on PEEK are less osteo conductive and bioactive than those on titanium.[10]

Pure PEEK implants

When comparing osseo integration of unmodified PEEK implants with other types of implants, pure PEEK showed lesser bone implant contact (BIC) when compared to titanium. Koch et al., in 2009 found that there was fibrous healing around PEEK implants and on histological evaluation there was significantly lower level of BIC around PEEK implants when compared to titanium.[13] Webster et al., in 2012 conducted a study in rat calvaria to evaluate the anti-infective and osseointegration properties of silicon nitride, PEEK and titanium implants. PEEK demonstrated significantly low resistance to bacterial infection after incubation with Staphylococcus epidermidis, which led to compromised osseointegration.[14]

Surface-treated PEEK implants

The use of physical surface treatment to produce bioactive PEEK has been extensively studied. Khoury et al. in 2015 modified PEEK using accelerated neutral atom beams (ANAB). This produced a nanotextured surface topography without adding external material or changing the chemistry of PEEK. This study demonstrated a significant improvement in osseointegration of ANAB-treated implants.[15] Several plasma treatments have been applied to PEEK. Poulsson et al., in 2013 compared osseointegration of unmodified PEEK, and oxygen plasma-treated PEEK and it was found that the osseointegration was significantly increased in the later.[16] Hassan et al. in 2018 treated PEEK with nitrogen plasma. The results proved that this modification exhibits higher osseointegration when compared to untreated PEEK in histological and mechanical investigations.[17] Chemical surface treatment has also been utilised to modify the chemistry of PEEK surface. Ouyang et al. in 2016 studied the effect of sulphonation using concentrated sulphuric acid on PEEK. The results revealed better osseointegration and antimicrobial ability on sulphonated PEEK than unmodified PEEK.[18]

Coated implants

Various studies have assessed the efficacy of coating PEEK implants with bioactive materials to improve their osseointegration. Spin-coated PEEK implants have higher bone-implant interface when compared to uncoated PEEK to decrease biofilm growth, which could prevent peri-implantitis and early implant failures.[12] Coating PEEK with titanium using e-beam deposition has shown to increase the hydrophilicity leading to enhanced cellular proliferation.[12] Tsou et al. in 2015 investigated whether titanium coating could achieve better osseointegration, TiO2 phases resulted in good bone formation on the implant surface and showed significantly more BIC in histological assessment in addition to higher shear strength in mechanical tests.[19] Different roughness of titanium coatings and combined Titanium/Hydroxyapatite (Ti/HA) coating on PEEK and carbon-fibre-reinforced (CRF)/PEEK were compared in a study by Stubinger et al., 2015 and they concluded that double coating showed the most favourable osseointegration.[20] Using titanium coatings, nevertheless could still lead to the very issues inherent to titanium i.e., hypersensitivity and increased stress levels at bone implant interface leading to increased bone resorption.

Keeping this in view, studies have focussed on other methods of surface modifications/ treatments. In Gas Plasma Nano etching of PEEK implants by exposing them to low power plasma gases like water vapour, oxygen/argon, and ammonia. It has been suggested that plasma treatment of PEEK introduces various functional groups on its surface which makes its surface more hydrophilic.[7] Several reports have shown that hydroxyapatite (HA) coating improves the osseointegration of PEEK implants. Nakahara et al. (2012) evaluated the HA coating on CRF-PEEK and the results revealed a higher shear strength of the coated implants in comparison to the uncoated one.[21] Lee et al. (2015) used cold-spray methods to apply a layer of micro-HA coating on PEEK. The results showed enhanced bone formation around the coated implants in histological and radiographical assessments.[22] Recent research has suggested that nano-sized particles of HA enhance osseointegration through mimicking cell-level n-HA.[23] Johansson's research group investigated n-HA coating on PEEK and revealed that the n-HA coated implant had significantly higher removal torque values, BIC ratio and BA than the uncoated PEEK.[24] Yang et al. (2017) have investigated the effect of n-HA/PEEK coated on to sandblasted, large grit and acid-etched (SLA) titanium implants using a peri-implantitis model. The authors concluded that coated SLA implants promoted better osseointegration and reduced inflammatory markers.[25] Chen et al. (2017) introduced the incorporation of fluorine on to PEEK surfaces. Fluorinated PEEK demonstrated good osseointegration and it exhibited good bacteriostatic ability in an in vivo study.[26] Bone morphogenic protein (BMP) coating on implants has been used to improve osseointegration. Guillot et al. (2016) evaluated the osseointegration of titanium and PEEK implants utilising a new BMP-2 delivery system and showed that BMP-2- coated implants have lesser BIC and bone formation.[27]

Bioactive composite implants

The incorporation of PEEK with bioactive materials has been suggested to improve its osseointegration. Many bioactive composite combinations with pure PEEK have been proposed. Ma et al. (2016), who investigated the use of compound and injection moulding techniques of different bioceramic nanoparticles of silicate and HA to yield biocomposites. The study revealed that both composites nano-calcium silicate (n-CS)/PEEK and n-HA/PEEK enhanced osseointegration. Additionally, n-CS/ PEEK demonstrated more BIC and bone formation than n-HA/PEEK and PEEK. Fibrous tissue was observed around the pure PEEK at 4 and 8 weeks postoperatively.[28] On the other hand, obtaining PEEK composites reinforced with carbon fibre and enhanced by nano-sized bioactive materials including HA and fluoro-hydroxyapatite (FHA) is a promising approach to improve both mechanical and bioactivity properties.[29]

Limitations:

PEEK is bioinert in nature and does not have any osteoconductive properties and when compared to Titanium, PEEK stimulates less osteoblastic differentiation. Like other polymers PEEK also have a hydrophobic surface, this reduces the cellular interaction and adhesion.[7] Due to its greyish brown colour PEEK is not suitable for monolithic aesthetic restorations of anterior teeth. More aesthetic material like composite should be used as a coating on the PEEK substrate to get an aesthetic result.[5] The osseointegration of modified PEEK remains debatable. To translate the use of PEEK implants to humans, preclinical evidence of satisfactory osseointegration and standardised outcome measures are still needed.

Conclusion:

PEEK is one of the few materials in dentistry possessing an elastic modulus similar to human bone. Besides this, modified PEEK is machinable to a high degree of precision and has optimal physical and mechanical properties, making it a desirable dental implant material. The main disadvantage seen in unmodified PEEK is the reduced osseoconductivity and bioactivity. Active research is revealing newer surface treatments that are capable of greatly improving the cell adhesion, proliferation, biocompatibility and osteogenic properties of PEEK to match if not excel those displayed by Titanium. The future is rife with promise for this exciting material and it could eventually result in PEEK becoming the next gold standard in dental implantology.

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