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*Review Article*

# Polyetheretherketone: A Crystalline Non-Metallic Plate: Past, Present and Future- A Review

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***ABSTRACT*:**
The use of Polyetheretherketone (PEEK) composites in the trauma plating system, total replacement implants, and tissue scaffolds has found great interest among researchers. There is a great revolution in recent years; this type of composites has been scrutinized for suitability as surrogate material over stainless steel, titanium alloys, ultra high molecular weight polyethylene (UHMWPE), or even biodegradable materials in orthopaedic and maxillofacial implant applications. Biomechanical and bioactivity concepts were contemplated for development of PEEK orthopaedic implants and a few primary clinical studies reported the clinical outcomes of PEEK-based orthopaedic/ cranial implants. Synthesis of PEEK composites broadens the physicochemical and mechanical properties of PEEK materials. To improve their osteoinductive and antimicrobial capabilities, different types of functionalization of PEEK surfaces and changes in PEEK structure were proposed. PEEK based materials are becoming an important group of biomaterials used for bone and cartilage replacement as well as in a large number of diverse medical fields. The possibility to use these materials in 3D printing process could increase the scientific interest and their future development as well. This study aims to reassess and converse the current concepts, biomechanical as well as bioactivity properties and its trending use in medical field as a maxillofacial and orthopaedic implants.
**Key words:** Polyetheretherketone, trauma plating, osteoinductive.

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**INTRODUCTION: {History and properties}**
Polyetheretherketone (PEEK) is a polyaromatic semicrystalline thermoplastic polymer with chemical formula (–C6H4–O–C6H4–O–C6H4–CO–)n [1]. PEEK was commercialized for the industry in the 1980s [2]. It was proposed as a material for biomedical application in 1998 by Invibio Ltd. In the same year Victrex PEEK business launched PEEK-OPTIMA for long-term implantable applications [2, 3].
Implants based on the PEEK composites have been developed as an alternative to conventional metallic or ceramic devices [4]. Polyetheretherketone forms: PEEK-LT1, PEEK-LT2, and PEEK-LT3 have already been applied in different surgical fields: spine surgery, orthopedic surgery, maxillo-facial surgery etc. PEEK-LT1 can contain varying amounts of bioactive materials like hydroxyapatite (HA) and b-tricalcium phosphate [table 1]. PEEK polymer devices were first reported for fracture fixation, using carbon reinforcement in a PEEK matrix [5]. Recent modifications were inculcated to PEEK plates to enhance the biocompatibility and strength of the material.
(PEEK) has been brought in biomedical field recently as the replacement of metal implant. The PEEK composites were projected as a superior biomaterial to treat the trauma, arthroplasty, or tissue loss injuries [1, 2]. The PEEK composite materials have been biomechanically tested and the strength of these materials has been assessed to use in load-bearing implants [3].PEEK is highly workable. Intraoperative modification and contouring are possible in the operating room using a high-speed drill with a cutting burr.Superior radiography properties, wear resistance, and fatigue strength of the

carbon fiber reinforced polyetheretherketone (CFRPEEK) have been extensively addressed by authors[3, 4].

**Shifting of paradigm from titanium implant to Polyetheretherketone :**

After ablative surgery of the mandible, angular-stable alloplastic reconstruction plates are commonly used[6]. Alloplastic reconstruction devices are the treatment of choice for many patients with the gold standard being titanium reconstruction plates [7,8]. The most comprehensive overview of this process is given by P. Sadr-Eshkevari et al in his meta-analysis out of the 14 articles reviewed, 944 patients presented with a mandibular defect. Defects were most commonly in lateral side of mandible and received conventional bridging plates [9]. Jewer DD et al. in his study named orofacial and mandibular reconstruction with iliac crest free flap: a review of 60 cases and a new method of classification dates back to 1989classified mandibular defect which is still followed and described three types: central [C-defect], hemimandibular [H-defect], and lateral [L-defect] [10]. However, reconstruction of mandibular defects with titanium bridging plates can have several complications such as plate exposure, plate fractures, and screw loosening [11, 12]. Various clinical studies have shown that using commercially available titanium plates for this type of reconstruction has repeatedly led to plate fractures or screws loosening [13-16]. The reasons behind these failures originate in the intensive notch plate design, the mechanical overload from stress, the moderately unfavourable mounting to the bone, and the substantive preliminary damage resulting from manual moulding to the individual jaw geometry by bending pliers [15, 17]. Additionally, a stress-shielding effect results from a combination of strong cyclic loading and the mechanical incompatibility of titanium and bone, which causes the loosening of screws in the bone tissue [18, 19]. As an alternative material to titanium, evidence and literature suggest the semi-crystalline, thermoplastic polymer PEEK due to its favourable biocompatibility and a bone-like Young‘s modulus of 3-4 GPa [20], PEEK appears promising for use in permanent implants. PEEK has been established as an implant material in the neurosurgical field, for example as cage [21] or for cranial defects [22]. Additionally, there are preliminary clinical studies for mandibular reconstruction in the relevant literature [23, 24].

**Clinical application of polyetheretherketone in maxillofacial reconstruction:**

The anatomical complexity of maxillofacial and cranial areas directs restoration of the forehead and orbital walls with perfect symmetry and good functional, morphologic and aesthetic results. As a result, biomaterials like titanium mesh or methylmethacrylate, which were earlier used as calvarial defects, are incongruous to reconstruct the orbital wall [25]. Autogenous grafts like, rib or iliac crest bone graft remain strenuous to shape and contour during reconstruction of fronto-orbito-temporal defects. Bone resorption can also often occur.

In the last few years PEEK material was recognized as a material for maxillo-facial and cranial reconstructions [25, 26]. This became possible with the computer-aided design (CAD) and computer aided manufacturing (CAM) technologies which enable manufacturing of very precise implants with complex morphology[3].

Scolozzi et al. in 2007 was first to document clinical application of PEEK material in cranial reconstruction [27].Two years later Kim et al.(2009) reported a series of four patients whose defects were reconstructed using customized PEEK implants. The authors followed the patients during a post-operative period of 16–20 months. None of the patients experienced implant-related complications such as infection, extrusion, or malposition and had excellent postoperative aesthetic and functional results. Goodson et al. [28] described a very complicated clinical case of successful use of a two-piece PEEK implant to reconstruct a fracture of the orbital rim and floor, and a flattened zygomatic complex. In 2014Jalbert et al. [29] applied a simple and reliable protocol to perform optimal primary reconstruction with a PEEK specific implant while performing resection for large lesions in the fronto-orbital region. They concluded that large and extensive resection can been accomplished in fronto-orbital region with excellent aesthetic and functional outcomes while reducing operating time and avoiding donor site morbidity.

Custommade implants allows for surgery with severe damage or wide resection of structural tissues of full thickness of the dome of the skull. In these cases, the cranioplasty, besides an obvious cosmetic advantage, restores the role of a physical barrier of the skull to trauma. Lethaus et al. [30] operated twelve consecutive patients. In seven cases customized milled titanium implants were inserted, in four cases PEEK implants were inserted and in one case an electron laser-beam melted titanium implant was inserted. This clinical study demonstrated that mechanical properties of PEEK are appropriate for reconstruction of the cranial defects. The elasticity and energy-absorbing properties of PEEK, which resemble bone more closely than titanium, provide better protection for cranioplasty in patients compared with titanium [30]. In 2015 O'Reilly et al. [31] have made a 6 year retrospective review of cranioplasty procedures in nineteen patients receiving 22 CT-based PEEK cranioplasty. Initial mechanism of injury was traumatic in 10/19 patients, neoplastic in 6/19, vascular in 2/19, and stroke in one patient. The PEEK plate required modification in four procedures. Three patients had reoperation following PEEK plate reconstruction. The authors concluded that use of CAD/CAM PEEK plate for cranial reconstruction has several advantages: ease of inset with excellent anatomic accuracy and aesthetic results; potential intra-operative time saving; the plate is also easily modified in the operating room [31].

The most common complications of cranioplasty are infections and exposure. Thien et al. [32] published in a retrospective cohort study the results of PEEK implantation on 132 patients who underwent cranioplasty with PEEK patient specific and preformed titanium mesh.

The overall complication rates for PEEK and titanium cranioplasty were 25.0 % and 27.8 %, respectively. PEEK had 3 of 24 (12.5 %) cranioplasty failures, whereas titanium had 27 of 108 (25 %) cranioplasty failures with a combined cranioplasty complication rate of 27.3 %.CFRPEEK (carbon fiber reinforced polyetheretherketone) implant bears lower stress due to the lower Young's modulus compared to the metal implants at similar strain and therefore more stress is transformed to the bone, resulting in normal physiological loading conditions on the bone. The Young's modulus of the 30% CFRPEEK is close to that of cortical bone and could acts as the supportive cortical bone structure for fracture healing. In this regard, some trauma plates have been made with 30% CFRPEEK with the same design as commercial titanium alloy plates. The lack of researches (FE analysis or experimental testing) for modification of CFRPEEK design proposes a wide range of investigations for development of the CFRPEEK trauma implants.

**PEEK for tooth replacement:**

The stress shielding and local inflammation observed with implants of titanium (Ti) and Ti alloy are considered to be the major causes of bone loss and implant failure. Some PEEK composites possess biomechanical characteristics similar to cortical bone and this could decrease the marginal bone loss and stimulate the implant osseointegration. Recently some newly designed PEEK implants for tooth replacement were proposed by different companies [3].

Lee et al. proposed an appealing study about the stress shielding and fatigue limits of PEEK dental implants [33]. Study reported that during compressive strength testing, the titanium rod bent until a 4 mm displacement without fracture, whereas the PEEK GFR PEEK, CFR PEEK (glass-fiber reinforced polyetheretherketone and carbon fiber reinforsed polyetheretherketone) specimens fractured. The fatigue limit of the 4 mm-diameter GFR-PEEK implant was found to be 310 N and is according to the ISO 14801 standard proposed for posterior tooth restorations. The static compressive strength of the 4 mm-diameter GFR-PEEK implant was 256 N. This is a promising result because increasing the diameter of the implants may adversely increase the stress shielding effect and marginal bone loss.

A Finite element analysis (FEA) of CFR-PEEK implants demonstrated that the CFR-PEEK dental implant showed higher stress peaks at the bone-implant interface due to a higher deformation, whereas the titanium implant showed a more homogenous stress distribution [34]. While in counter act another FEA study demonstrated that a CFR-PEEK implant with 60 % endless carbon fibers shows that this material distributed the stress in a similar manner as a titanium implant [35]

Other problems for clinical application of PEEK materials for dental implants are their radiolucency and their osseointegration and osseoinduction capabilities. One possible solution was to create a titanium coating on the surfaces of dental implants based on PEEK. Cook was the first who reported on the in vivo evaluation of bone contact, porosity, bone in growth, inflammatory response, and mode of failure of titanium coated PEEK implants. He placed 40 titanium-coated and uncoated PEEK implants placed in unicortical sites in femurs of dogs and observes a better osseointegration on titanium coated implants [36].

In dental prosthodontics: PEEK/ceramic crowns and for CAD/CAM milted fixed and removable dentures were recently proposed. Whereas in dental field PEEK materials are used like dental implants for tooth replacement but also like PEEK abutment for gingiva formation before the crown restoration [37, 38].

Recently electron beam deposition of thin titanium layer on PEEK surface was reported and shows potential approach to increase the biological activity of the implant surface [39].

**CONCLUSION:**

In the present scenario, PEEK versatile material and are largely applied in different surgical and medical fields. The PEEK based implants are an alternative of titanium based and ceramic implants in a cranial, maxillo-facial, orthopedic and spine surgeries. Further clinical trials and meta analysis is required to for its better understanding and applications.

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