Three-Dimensional-Printed Polyether Ether Ketone Implants for Orthopedics

Sir,

Manufacturing of personalized implant is the desired goal in the field of Orthopedics. Three-dimensional (3D) printing technologies have capabilities to fabricate patient-specific implants, devices, and instruments for the different fields of Medicine, including Orthopedics. The applications of 3D printing technologies are rapidly growing in the healthcare sectors for surgical planning, manufacturing of patient-specific implants, and developing anatomical models.[1] Polyether ether ketone (PEEK) is an organic compound material now being used in 3D printing for manufacturing of complex design geometry and patient-specific implants for Orthopedics. PEEK, as a material, was initially introduced in the 1980s, and now, it is a top-notch organic thermoplastic polymer, which is colorless, and the models developed from PEEK material show suitable quality for various application areas such as medical, automotive, aerospace, and other associated areas.[2] In the orthopedic field, it shows a significant impact for the manufacturing of load-bearing implants, which has somewhat similar properties as of human bone and also has lower wear resistance.[3] Moreover, the human body readily accepts PEEK material.

To manufacture Orthopedic implants, PEEK is an advanced biomaterial and suits well for catheters devices. Till now, only subtractive manufacturing methods such as computer numerical control machines were used to manufacture customized PEEK implants. However, this technique is time-consuming, expensive, and also waste material. Second, it is also difficult to give exact contours or required shape of the implant. 3D printing technologies readily fulfill these challenges and have various advantages as compared to traditional manufacturing technologies.[4]

With better technological developments, PEEK materials are now successfully used to manufacture customized orthopedic implants with the help of 3D printers.[5] These PEEK 3D-printed implants are primarily indicated and used for spine surgery, prosthetics, fixation of an osteotomy [Figure 1] and fractures [Figure 2], and reconstruction of complex calvarial and maxillofacial defects. Therefore, it is a suitable biomaterial which has columnar stiffness and is useful in reconstructive and orthopedic surgeries.[6]

PEEK 3D printing technologies provide greater design freedom, less waste, and reduced weight of implants that enhanced the performance of implants and provide satisfaction to the patient.[7] It has improved the durability of 3D-printed implants, tools, and devices used in orthopedics. It is used safely and has reduced the failure rate. The orthopedic surgeons are now using PEEK material to improve the biocompatibility of implants which are more bone-friendly. These materials are used in a wide range of implants applications and have become new standard biomaterial.[8]

Figure 1: A polyether ether ketone plate for fixation of high tibial osteotomy

PEEK materials are similar to human hard tissue and match with human body fluids. It has outstanding properties in orthopedics such as biocompatibility, osteoconductivity, nontoxicity, and noninflammatory nature and hence found a variety of applications in bone tissue engineering, restoration of periodontal defects, post teeth bleaching, and dental surgery. PEEK materials are also used as biomaterials in Orthopedic surgery, viz., trauma, osteotomy fixation, joint replacement, and spinal implants. These materials create an attractive platform and develop novel bioactive materials and dentistry.[9] In high temperature, PEEK materials have excellent chemical and mechanical properties, with a tensile strength of about 90–100 MPa and Young's Modulus of 3.6 GPa, and have 250°C useful operating temperature. It has properties such as high stiffness, high hardness, flexible, excellent sliding friction, excellent electrical properties, very minimal abrasion, good processability, excellent hydrolytic stability, and chemical resistance and does not tend to stress cracks.[10]

By the application of PEEK materials, the 3D-printed Orthopedics implants provide several advantages [Table 1] and can easily be fabricated with greater strength. In upcoming years, these materials will have a higher impact on different fields as engineering, medical, dentistry, and associated areas.[11] The only drawback of these PEEK implants, at present, is their higher cost as compared to conventionally used implants made up of stainless steel or

Table 1: Advantages of using polyether ether ketone implants in orthopedics

Biocompatible, nontoxic, and noninflammatory: PEEK implants are well suitable for orthopedics, spinal and trauma applications due to its biocompatible, nontoxic, and noninflammatory characteristic. It helps to explore new modifications for implant applications
Osteoconductive: PEEK materials are adopted now for making spinal implants, and it can be an excellent material to solve various problems in orthopedics
Lightweight: PEEK materials are low molecular weight polymer. These are used mainly in orthopedics in fracture and osteotomy fixation, spinal fusions, ligament reconstructions, etc., The applications of PEEK material are likely to find many more indications in the future
Excellent strength: PEEK materials are biocompatible material achieve high possible strength that bears the load of the human body. It provides better mechanical properties as compared to other conventionally used materials such as titanium
Radiolucent, on radiographs: PEEK materials are transparent to radiation and almost entirely invisible in X-rays photographs. Hence, it helps in assessing the fracture reduction and its healing
Customization, using 3D printing is possible: PEEK materials are printable using 3D printing technologies. Now, customized implants are more accessible to manufacture because 3D printing is quite successful in customized production and every patient and their problems are different
Compatible with CT and MRI: PEEK materials are compatible with CT and MRI technologies, and thus, these implants do not interfere with these imaging techniques

PEEK=Polyether ether ketone, CT=Computerized tomography, MRI=Magnetic resonance imaging

Figure 2: A radiolucent polyether ether ketone plate, after fixation of a three-part fracture of the proximal humerus

titanium. However, with increasing use and acceptability by the Orthopedic surgeons, the costs are likely to come down shortly.

However, PEEK possesses the deficient osteogenic properties, and the bio-inertness of PEEK limits its fields of application. Johansson *et al*. have tried to limit these drawbacks by coating the surface of PEEK with nanoscaled hydroxyapatite minerals.[12]

PEEK is reliable for the fabrication of patient-specific implants with complex geometry which is difficult to make by the traditional manufacturing process of the implant. In Orthopedics, it revolutionizes as one size does not fit to all situations and PEEK 3D printing technologies easily fulfill this requirement. Patient data are easily obtained from CT/MRI and is converted into 3D computer-aided design data. This technology can easily print these data with a layer thickness of 0.3 mm. These PEEK 3D-printed implants are then tested to check whether it would provide a long-term result and perform satisfactorily to the patient for surgery.[6]

In recent years, PEEK and its composites such as carbon fiber reinforced PEEK (CFR-PEEK) plates are increasingly being used. In a comparative study of 42 patients with proximal humeral fractures, the CFR-PEEK plates were compared with titanium plates, with a mean followup of 30.7 and 52.7 months, respectively. The shoulder mobility, clinical, and pain scores were reported to be similar, in both patient groups.[13] In a systematic review[14] of five published studies of lumbar spine fusion, using PEEK rods, the authors reported no statistically significant difference in the fusion success rate, pain, and functional improvement when compared with titanium rods at an average followup time of 24.1 ± 11.3 months. The PEEK implants for high tibial osteotomy were compared with the traditional metal implants in a cohort study of 41 cases, with a minimum 2-year followup. [15] No significant differences were found in the patient-reported outcomes, and the complications and reoperations were also similar for the PEEK and control groups.

The main limitation of this technology is a requirement of support structures that acquire extra cost. The accuracy of the implant is essential which depends on printing speed and the property of the PEEK material.

With this, in the future, the surgeons would be able to manufacture 3D-printed PEEK patient-specific implants in their clinics and hospitals, allowing them a perfect and creative innovation for their patients.

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Conflicts of interest

There are no conflicts of interest.

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