

# Polyether ether ketone (PEEK) and its manufacturing of customised 3D printed dentistry parts using additive manufacturing



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## ABSTRACT

**Background:** Identified research articles on Polyether ether ketone (PEEK) and its application in dentistry. Further identified the direction of evolution of this material through additive manufacturing (AM) in the field of dentistry.

**Materials and methods:** PEEK is one of the suitable thermoplastic polymers which is biocompatible for the human body. We have identified related research articles through Scopus. A bibliometric analysis helped to achieve the targeted research objective.

**Results:** Through Scopus search, 46 research articles were identified by using keywords as “PEEK” “Dentistry”. Doctors and scientists are using PEEK material in medical, and other associated fields to fulfil extensive requirements of customisation. Nowadays, PEEK is also being experimented in dentistry for developing implants and associated requirements. Therefore, by using AM technologies, PEEK-based implants provide a perfect match replica in lesser time and cost. Further, this paper identifies significant challenges of using this material with AM for dentistry. In the last, the paper identifies ten important application of PEEK in AM for dentistry.

**Conclusion:** Additive manufacturing shows a significant achievement in the design & development of dental implants, tools and devices using PEEK material. It helps in reduction of product development cycle time, cost, weight with improved quality of implants and helps fulfil various challenges faced in dentistry. This innovative technology works as concept generation and is easy to make a required modification for a product used in dentistry. Design and development of dentistry tool are done easily such as manufacturing of any implants for surgical planning and analysis whether the surgery will succeed or not. Therefore, this technology has application in the production of customised PEEK-based orthodontics, crowns, bridges, night guards and prosthodontics implants.

## 1. Introduction

PEEK is acknowledged as a high-performance polymer in engineering & medical applications due to its favourable mechanical and chemical properties.<sup>1</sup> In dentistry, there is a requirement of a material having excellent biocompatibility, good mechanical properties, resist high temperature, low moisture absorption and elasticity modulus, flexible and high resistance to chemical wear. All these properties are available in PEEK material, thereby making it suitable in the field of dentistry.

PEEK can be used as a raw material in additive manufacturing for making of a partial denture; crowns are manufactured as per individual anatomy of the patients. With the help of this technology, there is no restriction of design iterations during product development &

manufacturing as compared to other conventional manufacturing technology. PEEK as a material was introduced in the industry and is proven successful for dentistry. With the application of AM technology, PEEK implementation is increasing in dentistry as this material has suitable chemical and mechanical properties for the manufacturing of different dentistry implants.<sup>2</sup> Its applications are increasing due to superior biocompatibility of its implants and prosthetics.

Implants manufactured by PEEK are durable and lightweight which are successful in improving patient comfort. The application of AM in dentistry is also applicable to the manufacturing of removable partial denture network, fixed prosthetic and abutments.<sup>3,4</sup> The main advantage of PEEK 3D printed denture is its accuracy, and it is as per the match of individual patient's anatomy with other advantages of poor

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<sup>2</sup> <https://scholar.google.co.in/citations?user=rftyiwvsAAAAJ&hl=en>.

electrical & thermal conductivity, x-ray, durability, lightweight & scanner friendly.

## 2. Research objectives of the paper

Dentistry profession requires customised implants and parts as per individual patient's requirements. This requirement can be undertaken by using PEEK material in additive manufacturing to create innovation as this provides appropriate mechanical strength, stiffness and durability.<sup>5,6</sup> AM is used in reverse engineering, product design & development, and production of concept models, can now be well used to create PEEK-based parts for dentistry application. The manufactured part seems to have a good patient fit and may help speedy recovery of the patient. Therefore, this study is conducted to fulfil the following research objectives:

- I. To study the PEEK applications in dentistry and its manufacturing through additive manufacturing
- II. Identify different challenges taken by additive manufacturing in dentistry with some limitations
- III. Identified research status of PEEK in dentistry through Scopus and analyse year wise trend of publications, identify different journals and sources publishing research articles
- IV. Identify the broad process of manufacturing PEEK-based implants through the additive manufacturing
- V. Identifying the significant applications of PEEK in dentistry

## 3. Polyether ether ketone (PEEK)

In the early 1980s, PEEK was introduced as a high-performance engineering thermoplastic that resists higher temperature. It has excellent long-term chemical resistance and a unique combination of mechanical properties. PEEK material has a melting point of 343 °C and high glass transition temperature of 143 °C. Due to PEEK properties, this material is used in automotive, aerospace, structural, biomedical and high-temperature electrical applications.<sup>7,8</sup> This material is processed by conventional methods such as extrusion, injection moulding and compressed moulding, and now, in the form of a wire, is used by Fused deposit modelling (FDM) technology of AM.

FDM, successfully print parts and offers possibilities for the manufacturing of higher strength biocompatible lightweight parts. It exhibits satisfactory tensile property and creep's resistance. In dentistry, this material can replace aluminium for the manufacturing of implants, instruments and required parts. It offers necessary stability to withstand steam, hot water, chemicals and solvents. PEEK provides long term operating reliability in a fluctuating range of pressure, temperature and frequency.<sup>9,10</sup> Now, this material is also used in regenerative pumps, pipes and other parts that withstand high temperature and pressure.

By using FDM technology, one can develop complex design geometry PEEK implants, which were not previously possible by conventional manufacturing technologies. It usually requires a nozzle temperature between 360–400 °C and heated bed of 120 °C. It is suitable for dentistry due to its low moisture absorption as compared to other material such as Acrylonitrile Butadiene Styrene (ABS). Therefore, PEEK being a polymeric material can be used for the manufacturing of implants, fixed and removable dental prostheses, double crown removal dental prosthesis which can effectively be used for interim restoration.<sup>11</sup>

## 4. Benefits of PEEK in dentistry

PEEK has good mechanical properties, excellent chemical-resistance, high-temperature stability, non-cytotoxic, tissue-compatible, electrically non-conductive, bio-inert and thermally insulating.<sup>12,13</sup> Some other benefits of PEEK making it suitable for dentistry are the poor electrical & thermal conductivity with low friction. Parts made with PEEK show a tensile strength of 90–100 MPa and Young's modulus of 3.6 GPa. It

creates innovation in dentistry which helps to fulfil various requirements in dentistry. PEEK manufactured dentistry implants easily implemented in the patient's mouth that help to speedy recover the patient. Due to the excellent properties of this material, implants assist required to load and pressure which increases the success rate of operation. It also offers lesser weight as compared to other traditional material used in dentistry and provides a natural feel to the patient with efficient performance.<sup>14</sup>

## 5. Additive manufacturing

Additive manufacturing undertakes product manufacturing from a 3D file which is imported in Standard Triangulate Language (STL) format, which divides CAD drawings into a very thin section and enables manufacturing layer by layer. It can produce parts without the need for any tool or mould. As compared to subtractive manufacturing technologies such as milling, Computer numerical controlled (CNC) machine, additive manufacturing provides advantages of higher flexibility, integration of functions, and design freedom.<sup>15</sup> In the starting, AM was used for making master patterns, functional prototypes, tools and devices with different shape and size.<sup>16</sup> Nowadays, there are different types of AM manufacturing technologies, and support software, well applied to decrease the product development cycle time. This new upcoming technology is an essential tool for digital manufacturing and rapid product development.<sup>17,18</sup> Therefore, modification of any dentistry product can also be possible quickly as per requirements. It speeds up the research & development process and decreases commercial risk.

## 6. Different types of 3D printing technologies

Various 3D printing technologies are being used to create the final product in the desired shape and size. In AM technology, functional components are possibly manufactured directly from a digital file. Therefore, tool dies, jigs and fixture are required for manufacturing of part.<sup>19,20</sup> AM technologies consist of 3D printing, 3D scanning and software supports. Various 3D printing technologies are as follows:

- Selective Laser Sintering (SLS)
- Fused Deposition Modelling (FDM)
- Stereolithography (SLA)
- Multijet 3D Printing (MJP)/Polyjet 3D Printing (PJP)
- Digital Light Processing (DLP)
- Direct Metal Laser Sintering (DMLS)
- Selective Deposition Lamination (SDL)
- Binding Jetting printing (BJP)/Projet 3D Printing (PJP)
- Electron Beam Melting (EBM)
- Laminated Object Manufacturing (LOM)

Out of the above printing technologies which are now part of additive manufacturing, FDM technology is mostly preferred to print PEEK parts.<sup>21</sup> In the current scenario, the primary applications of parts manufactured by this technology are useful as functional parts, tooling components, patterns for metal castings, models for prototype tooling, fit and assembly, presentation models, visual aids, research and teaching.<sup>22</sup>

3D modelling software is having many potential applications like capabilities of graphics and product design. These are used for design analysis and modification such as for reverse engineering. These create a different format of the file and for the printable format used in 3D printing technologies. Different software used for 3D designing of product/part discussed as under:

### 6.1. Solidworks

Professional 3D designers use this software. It includes advanced features such as reverse engineering, design validation. It provides exact features as per requirements such as detail curvatures and edges.

## 6.2. Fusion 360

Fusion 360 is cloud-based 3D CAD software used to design complex product. A different option like solid, freeform and mesh modelling is available in this software. This software regularly updates its features after a while as per demand.

## 6.3. AutoCAD

This software is widely used in 3D modelling by graphical and industrial designers. It can be made any complex shape object and easily printable in 3D printing technologies.

## 6.4. 3DS max

This is 3D modelling, simulation, modelling and rendering software used to create product design, games, film and motion graphics. It also provides more believable texture such as human-like motion. It focuses on animation such as polygon modelling, parametric mesh modelling and shading tools.

## 6.5. Rhino

Rhino software is used to create precisely 3D models surface. It is used in industrial, architecture, multimedia and product design. It is used to manufacture more complicated shape product such as designing of jewellery.

## 6.6. Inventor

It is 3D mechanical design software used by different professional having direct, freedom and parametric modelling choices. It is the best tool for simulation and automation.

## 6.7. Moment of inspiration (MoI) 3D

It is a powerful tool used for polygonal modelling. It has the advance function for the designing of a hard surface. It is a user-friendly used to create curved surfaces.

## 7. Manufacturing of PEEK implants through the additive manufacturing

Additive manufacturing is used to create patient-specific 3D dentistry implants, denture, tools and devices as per patient match with the help of 3D printing technologies, 3D scanners and support software. PEEK is a useful material for dentistry to produce implants which seems useful for the patient.<sup>23,24</sup> There are various steps adopted to create customised PEEK dentistry implants using AM as discussed under:

### 7.1. Capturing patient data

Dental 3D scanner and other scanning technologies are used to capture complex and surface data. These technologies precisely scan patient mouth and teeth.

### 7.2. Creation of 3D CAD model

After scanning, the image captured by different scanning technologies is modified further by using customised software like mimics, Ansys, Solid Works, 3D doctor, 3D slicer etc. to create a printable version of the data. Then, this 3D CAD model is further modified and validated through software. Final output data is converted further into STL file format or other required file formats for product printing.

### 7.3. Printing of part by using additive manufacturing

PEEK dentistry model in 3D is easily manufactured using the input of CAD file. This technology is reliable to manufacture precise teeth as compared to another traditional manufacturing process and can be cost-effective as there is lesser wastage of raw material.

### 7.4. Post-processing and testing

After printing of the part, post-processing is also done to improve the strength or surface finishing or provide important characteristics as per requirement. This part is tested further before the actual implementation.

### 7.5. Clinical application

Dentist can also use this patient-specific part to perform actual surgery to improve accuracy and patient satisfaction.

Additive manufacturing is an innovative approach to modern manufacturing. The dentist can take advantage of this set of technologies for research purpose, along with the design and development of teeth, dentures, crown, braces, veneers and aligner. It is useful for complicated cases which help to improve patient satisfaction.

## 8. Different challenges of dentistry well taken by additive manufacturing

In dentistry, patient data is different, so there is a requirement of customised implants/part which can quickly be developed by using AM at lesser cost and time. In this process, we required 3D digital data easily captured by dental 3D scanner/designing software and printable by 3D printing technologies. These implants/parts are high performing as compared to standard parts manufactured by the conventional method of the machining process. These machining processes are costly as compared to manufacturing a customised product. AM reduces the wastage of material because the material is added layer by layer; whereas, in the machining process, there is a higher wastage of material. This technology plays a vital role in product development, and with technological developments and massive scale of usage, there will be a lower cost of production. Therefore, it provides a modified concept to dentistry by which changes in dentistry part can be done quickly by creating 3D CAD model either by designing software like CATIA, Solid Works, etc. or by 3D model and printable by this technology as per desired shape and dimension. Table 1 discusses various challenges in dentistry that are being fulfilled by the adoption of additive manufacturing along with related limitations.

Additive manufacturing plays an important role to enhance the design & development ability of products used in dentistry. It quickly identifies the mistakes in assembly by validating the assembly process. Nowadays, AM is appropriate in product development and training purposes. It shortens research & development time for new products. AM technologies create innovation by which these technologies are applied for the concept generation phase of the design and development process. In this process, concepts models are created and choose best and check whether it is suitable or not. Thus, AM seems helpful for dental researchers, students and practitioners.

## 9. Research status on PEEK in dentistry

The research on PEEK applications in dentistry is increasing. Taking data from Scopus by searching keywords as “PEEK” “dentistry” identified 46 articles are published so far up to Feb 2019. The first paper published on PEEK in dentistry in 1997, and for the next paper, there was a gap of seven-year (in 2004). Again, there was a gap of five years, and the third paper was published in 2009. After 2009, there was continuously published a paper in each year. In 2010 (3), 2011 (1), 2012 (1), 2013 (3), 2014 (5), 2015 (2), 2016 (7), 2017(12), 2018 (6)

**Table 1**  
Additive manufacturing in dentistry: capabilities and limitations.

S No	Attributes	Capabilities	Limitations	References
1	Incremental & disruptive innovation	<ul style="list-style-type: none"> <li>This technology provides an incremental innovation in the dentistry</li> <li>Provide radical changes and fundamental shift in making &amp; designing</li> </ul>	<ul style="list-style-type: none"> <li>Most of the people are ignorant about this its innovative technologies</li> <li>Low mechanical strength as compared to metals and ceramics</li> <li>Requires new materials and need for more research</li> <li>Not suitable for a mass production system</li> </ul>	Vaezi and Yang, 2015 <sup>25</sup> ; Steenhuis and Pretorius 2017 <sup>19</sup> ;
2	Development costs	<ul style="list-style-type: none"> <li>It plays an important role in the reduction of product design &amp; development cycle time and associated cost of the model</li> </ul>	<ul style="list-style-type: none"> <li>Lack of information on new technologies in the market players</li> </ul>	Maji et al., 2014 <sup>26</sup> ; Haleem et al., 2019 <sup>27</sup>
3	Time-to-market	<ul style="list-style-type: none"> <li>Ability to drastically reduce time to produce models, parts or prototype</li> <li>It shortens time to market</li> </ul>	<ul style="list-style-type: none"> <li>The very high cost of the machines and even raw material</li> </ul>	Tunchel et al., 2016 <sup>29</sup> ; Javaid and Haleem 2017 <sup>30</sup>
4	Communication	<ul style="list-style-type: none"> <li>It helps a designer to visualise innovatively</li> </ul>	<ul style="list-style-type: none"> <li>There are very few manufacturers with lots of patents, and the printing process is a black box to users</li> </ul>	Ramola et al., 2019 <sup>31</sup> ; Honigmann et al., 2018 <sup>34</sup>
5	Unique full-colour	<ul style="list-style-type: none"> <li>Provides better communication with different stakeholders</li> <li>Uniquely enables to provide full colour to active learning in the field of dentistry</li> </ul>	<ul style="list-style-type: none"> <li>Involves in limited numbers</li> <li>The high cost of machines</li> <li>Highly qualifies technology support required</li> </ul>	Ejaz et al., 2014 <sup>32</sup> ; Li et al., 2018 <sup>33</sup>
6	Operating costs	<ul style="list-style-type: none"> <li>It is a time-efficient and cost-effective approach</li> <li>Low operating cost if non-patented technology is used</li> </ul>	<ul style="list-style-type: none"> <li>Material cost is high</li> <li>The software is quite costly</li> <li>Highly qualified technicians are needed</li> <li>Patented machines are quite expensive and if they are used less then product cost is prohibitive</li> </ul>	Ingole et al., 2009 <sup>34</sup> ; Li et al., 2018 <sup>33</sup>
7	Print speed	<ul style="list-style-type: none"> <li>Superior quality and speed of printing used with a wide variety of material</li> <li>Increase in layer thickness can be built the product in lesser time</li> </ul>	<ul style="list-style-type: none"> <li>High printing speed decrease the quality of the product</li> </ul>	Negi et al., 2018 <sup>35</sup> ; Amola et al., 2019 <sup>31</sup>
8	Efficiency in design and manufacturing	<ul style="list-style-type: none"> <li>Applicable in different medical applications</li> <li>AM increase efficiency in design and manufacturing of dentistry products by the input of good quality material</li> </ul>	<ul style="list-style-type: none"> <li>In some AM technologies material changing option is limited which affect the efficiency of the final product</li> <li>Highly qualified human resources and software required</li> </ul>	Honigmann et al., 2018 <sup>34</sup> ; Javaid and Haleem, 2018 <sup>36</sup>
9	Eco-friendliness	<ul style="list-style-type: none"> <li>Provides good potential and flexibility of design and manufacturing in a single unit with a safe and eco-friendly environment</li> <li>There is lesser wastage of raw material which helps to provide a safe environment</li> </ul>	<ul style="list-style-type: none"> <li>New machines are coming up</li> <li>The size limitation of the product as large size machines are quite expensive</li> </ul>	Basgul et al., 2018 <sup>7</sup> ; Martinsuo and Luomaranta, 2018 <sup>37</sup>

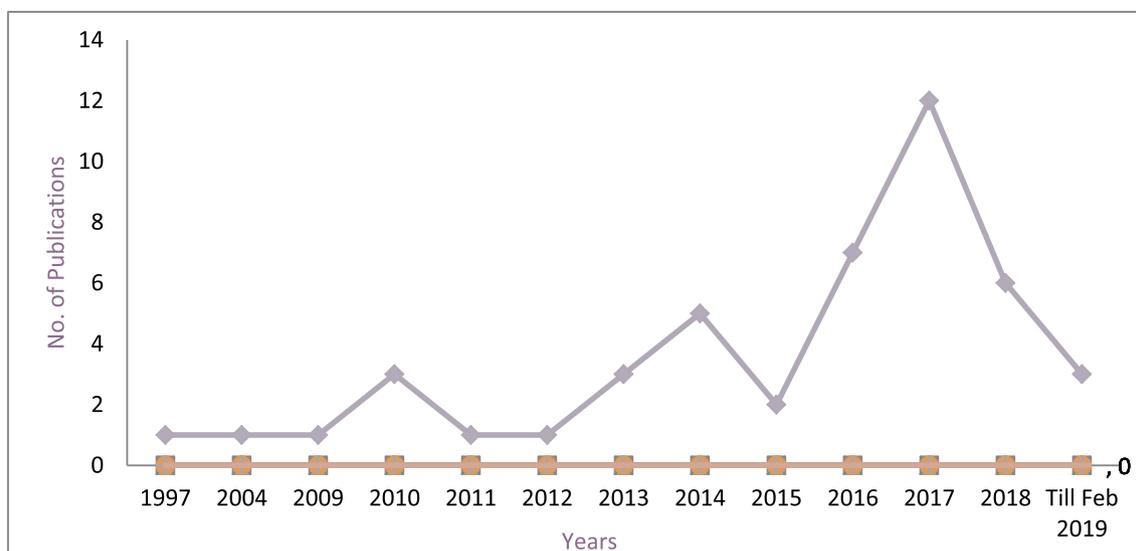


Fig. 1. Year-wise publications on PEEK in dentistry (Source: Scopus).

and in this present year 2019 up to Feb, three articles are published so far. This year wise publication is shown in Fig. 1.

There different journal and sources published research articles on PEEK in dentistry. Journal of prosthetic dentistry published maximum publication of 12 articles. Journals “Dental Materials”, “Stomatologija”, “Journal of Indian prosthodontist society”, “Journal of the mechanical behaviour of biomedical materials” published two papers by each journal. The journals included are: “ACS applied materials and interfaces”, “Actachirurgiaeorthopaedicae et traumatologiaezechoslovaca”, “Bionanomaterials”, “Clinical epidemiology and global health”, “Clinical oral implants research”, “Compendium of continuing education in dentistry Jamesburg N J 1995”, “Composites science and technology”, “Dental Cadmos; General dentistry”, “High performance polymers”, “International Journal of oral and maxillofacial implants”, “Journal of biomaterials science polymer edition”, “Journal of materials science materials in medicine”, “Journal of polymer engineering”, “Journal of prosthodontic research”, “Journal of prosthodontics”, “Key engineering materials; Materials chemistry and physics”, “Materials science and engineering C”, “Nederlandstijdschriftvoortandheelkunde”, “Zeitschrift fur zahnarztlicheimplantologie”, “Plus one”, “Oral and maxillofacial surgery”, “Virtual and physical prototyping”, “Revista de Chimie”, and “New York state dental”, journal.

Going through the area wise contribution of research publication on PEEK in dentistry, the maximum contribution of 32% is from the dentistry field. Other contributors are from fields like materials science (18%), Engineering (16%), Medicine (14%), Chemical engineering (6%), Biochemistry, Genetics and molecular biology (4%), Chemistry (3%) and others (7%). Another field is for contributions from Physics, astronomy, Agricultural, Biological Sciences, Computer science and Mathematics.

## 10. Applications of PEEK in dentistry using additive manufacturing

There are various applications of PEEK 3D printed partial denture having a lightweight, durable and improved patient comfort. Table 2 discussed different applications of PEEK in dentistry using additive manufacturing.

PEEK is a high-performance polymer that can be successfully printed using FDM technology of AM. Now additive manufacturing technologies are also available to print smart materials, commonly known as 4D printing. These smart materials products can change the shape with respect to time with the variation of temperature.<sup>58</sup> In healthcare, there is a

significant requirement of research and innovation.<sup>59</sup> PEEK material gains numbers of the user in the field of prosthetic dentistry due to its outstanding capability. In clinical practice, PEEK implants seem to provide benefits to the patients.<sup>60,61</sup> It manufactures dentures as well as crowns, bridges and other dentistry requirements. This material provides a good result, by which a double-crown retained dental prosthesis is manufactured and implemented in the 16 years old patient, satisfactory results are reported.<sup>50</sup> Another case of a 32-year-old patient, in this case, patient teeth was lost six years back. Here seven grams of PEEK material was used to manufacture artificial teeth. This show satisfactory result and high comfort to the patient due to its light weight.<sup>40,62</sup>

## 11. Discussion

Additive manufacturing is a disruptive innovation-based technology which provides a high potential to change the contemporary manufacturing system. It has less material wastage, and part manufacturing is quite precise as the material is added layer by layer as per the exact requirements, whereas in machining process there is considerable wastage of raw material & energy in shaping the raw material and final finishing it to precise requirements. The significant reason for AM is its capabilities of product customisation, and this is being well acclaimed in the upcoming areas of medicine, dentistry, aerospace, automobile, food, defence and manufacturing. Patient's anatomy and requirements are captured through a dental digital 3D scanner or traditional scanning devices. Now specialised 3D scanners are available and can be used efficiently for capturing complex data of the patients both surface & the bones. AM is used to manufacture customised 3D implants, fixed and removable dental prostheses, denture, orthodontics, crowns and bridges, double crown removal dental prosthesis. One can also use 3D dental models to build a custom mould with high accuracy. PEEK implants replaced metallic and ceramic material for dentistry applications.

## 12. Future scope

In upcoming years, additive manufacturing will bring improved and low-cost PEEK-based 3D printed product for clinical and dentistry laboratory. These PEEK implants as compared to other plastic material remain stable for a longer life due to its high resistance to wear. Dental implants are the substitute for teeth or bones; as artificial implants should also have the same property. These PEEK 3D printed dental implants provide a requisite modulus of elasticity and fatigue strength. PEEK with AM will provide a disruptive effect by efficiently

**Table 2**  
Applications of PEEK in dentistry using additive manufacturing.

S No	Applications	Description	References
1	Customised dental implant	<ul style="list-style-type: none"> <li>•AM provides an excellent solution to manufacture customised PEEK dental implants in lesser time and cost</li> <li>•Manufacturing of PEEK implants through AM is precise as compared to the traditional manufacturing method</li> </ul>	Lee et al., 2012 <sup>38</sup> ; Schwitalla et al., 2015 <sup>39</sup>
2	Fixed and removal dental prostheses	<ul style="list-style-type: none"> <li>•To reconstruct the defect of missing teeth, one can manufacture prostheses which are used inside the mouth</li> <li>•Also applicable to the manufacturing of hard structure of jaws</li> <li>•Applicable for the manufacturing of both fixed and removable prostheses to attach teeth and surrounding muscles</li> </ul>	Sinha et al., 2017 <sup>40</sup> ; Basgul et al., 2018 <sup>7</sup>
3	Modification in dental implants	<ul style="list-style-type: none"> <li>•Quick modification in any dentistry model to create any required innovation</li> <li>•Data of the patient is quickly captured by using a dental 3D scanner and modified by using different design software</li> <li>•Easily print customised 3D PEEK dental implants with required shape and size</li> </ul>	Vaezi and Yang, 2015 <sup>25</sup> ; Rahmitasari et al., 2017 <sup>41</sup> ; Haleem and Javaid, 2018 <sup>42</sup>
4	Denture	<ul style="list-style-type: none"> <li>•Easy replacement through PEEK-based artificial teeth</li> <li>•Implants manufactured by this material are biocompatible and supports soft and hard tissue in surrounding of teeth</li> <li>•Provide natural appearance to the patient face as original and help provide support to lips and cheeks</li> </ul>	Schwitalla et al., 2013 <sup>43</sup> ; Selim et al., 2018 <sup>44</sup>
5	Increase biocompatibility	<ul style="list-style-type: none"> <li>•PEEK has excellent biocompatibility which absorbs less moisture and is useful for the manufacturing of surgical instruments</li> <li>•PEEK made parts are not allergic to skin and human tissue</li> <li>•PEEK is one of best dentistry grade material having excellent visibility and radiography property</li> </ul>	Lu et al., 2016 <sup>45</sup> ; Schwitalla et al., 2016 <sup>46</sup>
6	Orthodontics	<ul style="list-style-type: none"> <li>•AM can be effectively used to manufacture innovative PEEK orthodontics applications for a patient without extraction and pain</li> <li>•Used for design and manufacturing of dental appliances as needed for treating tooth irregularity</li> <li>•Helpful to control mandibular and maxillary bones growth during treatment</li> </ul>	Xu et al., 2015 <sup>47</sup> ; Basgul et al., 2018 <sup>7</sup>
7	Crowns and bridges	<ul style="list-style-type: none"> <li>•PEEK manufactured crown and bridges help to create a bond between implants and existing teeth</li> <li>•It helps to recreate the natural contour of teeth and provides a proper combination of upper and lower teeth</li> <li>•Applicable to prevent spreading of cracks of teeth and cover implants</li> </ul>	Liebermann et al., 2016 <sup>48</sup> ; Vaezi and Yang, 2015 <sup>25</sup>
8	Double crown removal dental prosthesis	<ul style="list-style-type: none"> <li>•Double crown removal dental prosthesis manufactured by PEEK material provides better retention and support between multiple abutment teeth</li> <li>•Tested for support to retain tooth mucosa and implants</li> </ul>	Zoidis et al., 2015 <sup>49</sup> ; Hahnel et al., 2018 <sup>50</sup> ; Haleem and Javaid, 2019 <sup>11</sup>
9	Replace metallic and ceramic materials in dental applications	<ul style="list-style-type: none"> <li>•PEEK parts can replace metallic and ceramic material due to its greater design freedom, enhanced performance and lower friction, but to limited applications</li> <li>•This material can perform satisfactorily in the extreme chemical environment</li> <li>•In dentistry, this material is used as a superstructure and implant body to increase performance</li> </ul>	Costa-Palau et al., 2014 <sup>51</sup> ; Haleem et al., 2018 <sup>52</sup> ; Wachtel et al., 2019 <sup>53</sup> ; Brum et al., 2019 <sup>54</sup>
10	Improve patient comfort	<ul style="list-style-type: none"> <li>•In dentistry, PEEK is biocompatible material which is comfortable to the patient</li> <li>•Provides ability to perform the desired function over a time duration</li> <li>•3D printed Implants are implemented into the patient mouth without causing deleterious changes</li> </ul>	Kurtz and Devine, 2007 <sup>55</sup> ; Zoidis et al., 2015 <sup>56</sup> ; Zhang et al., 2019 <sup>57</sup>

manufacturing implantable devices using additive manufacturing which will help the traditional dentistry. In future, it provides several benefits like increased efficiency and effectiveness of the design process and delivers new customised products at a cheaper and faster rate. The design and quality of any product can be improved by making a prototype and tested.

### 13. Conclusion

Additive manufacturing provides a good solution for the manufacturing of customised PEEK 3D dentistry models when there is a requirement of exact fit model. This technology is available for on-demand production in dentistry and makes surgeons job easier. A dentist can now convert the complex requirements into reality by producing innovative products with lesser material & time waste. PEEK material has great potential for the replacement of tooth and seems cost effective for dentists. The importance of this material is increased due to its aesthetic demand and superior biocompatibility. Now a day's patient avoids incorporating metallic material in the mouth; thus PEEK-based implants can take this place. AM technology is applicable for direct

manufacturing of various other dentistry tools and guides. A 3D printed PEEK part is lightweight, and this technology helps in manufacturing a robust denture, thereby improving the comfort of the patient. Therefore, a 3D manufactured PEEK implants provide better safety and satisfaction to the patient. The future of PEEK-based 3D printed parts seems bright in the field of dentistry.

### Conflicts of interest

None.

### Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.cegh.2019.03.001>.

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