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REVIEW ARTICLE

THE APPLICATIONS OF POLYETHER-ETHER-KETONE (PEEK) IN DENTISTRY: SYSTEMATIC REVIEW

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ABSTRACT

Background: Virtual reality simulators, whether based on haptic reality or the use of models, are becoming an essential element of modern education. The benefits of virtual reality in dentistry are constantly being evaluated as a method or adjunct to improve fine dexterity, eye-hand coordination in preclinical settings and to overcome the monetary and intellectual challenges inherent in such training. **Context:** polyetheretherketone (PEEK) is one of the most used semi-crystalline thermoplastic polymers in aeronautics and aerospace. This new material matches the technological advancements and patient's desires for a natural and aesthetic look, thanks to its strength, superior biocompatibility, low plaque affinity and aesthetics characteristics close to the desired natural dental structure **Objectifs:** The purpose of this study is to review polyetheretherketone (PEEK), its performance and its different uses in dentistry. **Material and methods:** The Research was about PEEK and its uses in dentistry between January 2012 and April 2019 in Medline via PubMed, Google Translate, Google Library. 19 articles in text integral were selected and used in this review. **Results:** 237 articles were found in the database with the following keywords: PEEK, prosthodontics, dentistry. PEEK polymer adhesion data were used as various uses of PEEK. **Conclusions:** The PEEK polymer is suitable for several uses: in pedodontics, orthodontics, fixed and removable dental prosthesis and maxillofacial prosthesis.

Keywords: *PEEK, polymer, dental prosthesis, dentistry.*

1. INTRODUCTION

At the end of the twentieth century, new polymer molecules were discovered such as poly (oxy-1,4-phenylene-oxy-1,4-phenylenecarbonyl-1,4-phenylene) designated by Poly Ether Ether Ketone- (PEEK). The development of this material began at Imperial Chemical Industry (I.C.I). Currently, it is produced primarily by the Victrex® company based in England, but a competitor appeared in 2003, Gharda Chemical Ltd. established in India. The discovery of the exceptional physical properties of these polymeric materials has brought a considerable technological advance, mainly in the composites industry. Nowadays it is widely known that PEEK is a high-performance semi-crystalline thermoplastic material, characterized by excellent chemical, thermal and mechanical stability. Thepolyetheretherketone is commonly used in advanced technology and precision. It's Young's modulus is about 3.2 GPa at room temperature and operating temperatures up to 260 ° C. Indeed, PEEK is one of the thermostable polymers. It has a glass transition temperature Tg of the order of 143 ° C, and a melting temperature Tf of around 330 ° C. Currently, the PEEK has found a good place in the aerospace and automotive industries. At the same time, PEEK is characterized by good resistance to chemical and biochemical degradation against the majority of conventional solvents and dissolves only in certain concentrated acids such as sulfuric acid, methanesulfonic acid or hydrofluoric acid. Thus the PEEK is an ideal candidate for industrial applications involving harsh environments. Due to its thermal and mechanical properties, and its high chemical resistance, PEEK is one of the most used semi-crystalline thermoplastic polymers in aeronautics and aerospace. This is the reason why a lot of work is currently done on PEEK [1], particularly in the field of interfacial resistance improvement in composites, adhesion and long-term behavior.

Synthesis and crystallinity:

PEEK belongs to the Poly-aryl-ether-ketone family. Historical synthesis of PEEK has been achieved by polycondensation of bisphenol with dihalides activated with dimethylsulfoxide (DMSO) as the solvent and a base such as NaOH [2]. These high molecular weight polymers were difficult to obtain because of the crystallinity and the resulting non-solubility in DMSO. To work around the problem of solubility Attwood and Rose used diphenyl sulfone as a solvent to obtain a high molecular weight PEEK [3]. Polymerization was conducted near the melting point of the polymer to maintain solubility. (I.C.I) commercialized the first high molecular weight PEEKs synthesized by this method in 1982.

PEEK can be obtained either in the quasi-amorphous state or in the semi-crystalline state depending on the cooling rate from the molten state. This phenomenon is associated with the rigid structure of the polymer (aromatic nucleus). For the same reason, the maximum crystallinity rate of PEEK is low (max ≈ 40%) in comparison with conventional polyolefins such as polypropylene (max ≈ 70%) [2,3].

2. MATERIALS AND METHODS

The literature search covered the following databases: Medline via PubMed, Science Direct, Wiley's online library, and Google Scholar web search sources dated from January 2012 to April 2019. Titles and abstracts were reviewed. Some study topics were not appropriate for this review, others were mentioned in different databases. In the end, 19 full-text articles met the inclusion criteria (Figure 2).

2.1 Inclusion criteria

Articles exclusively in English concerning the use of PEEK for the manufacture of denture and implant-supported prostheses, inlay-cores, veneers, claps, removable partial denture, maxillofacial obturators, pedodontic space maintainers and orthodontic wires; despite manufacturing methods, surface modifications, type of investigation (in vitro or in vivo), type of scientific articles (case reports, original research, review articles). The period of the selected articles was from January 2012 to April 2019. Exclusion criteria: articles reporting the use of PEEK for the realization of dental or maxillo-facial implants, PEEK used as material for or bone regenerative, articles reporting orthopedics uses of PEEK and articles reporting the use of PAEK.

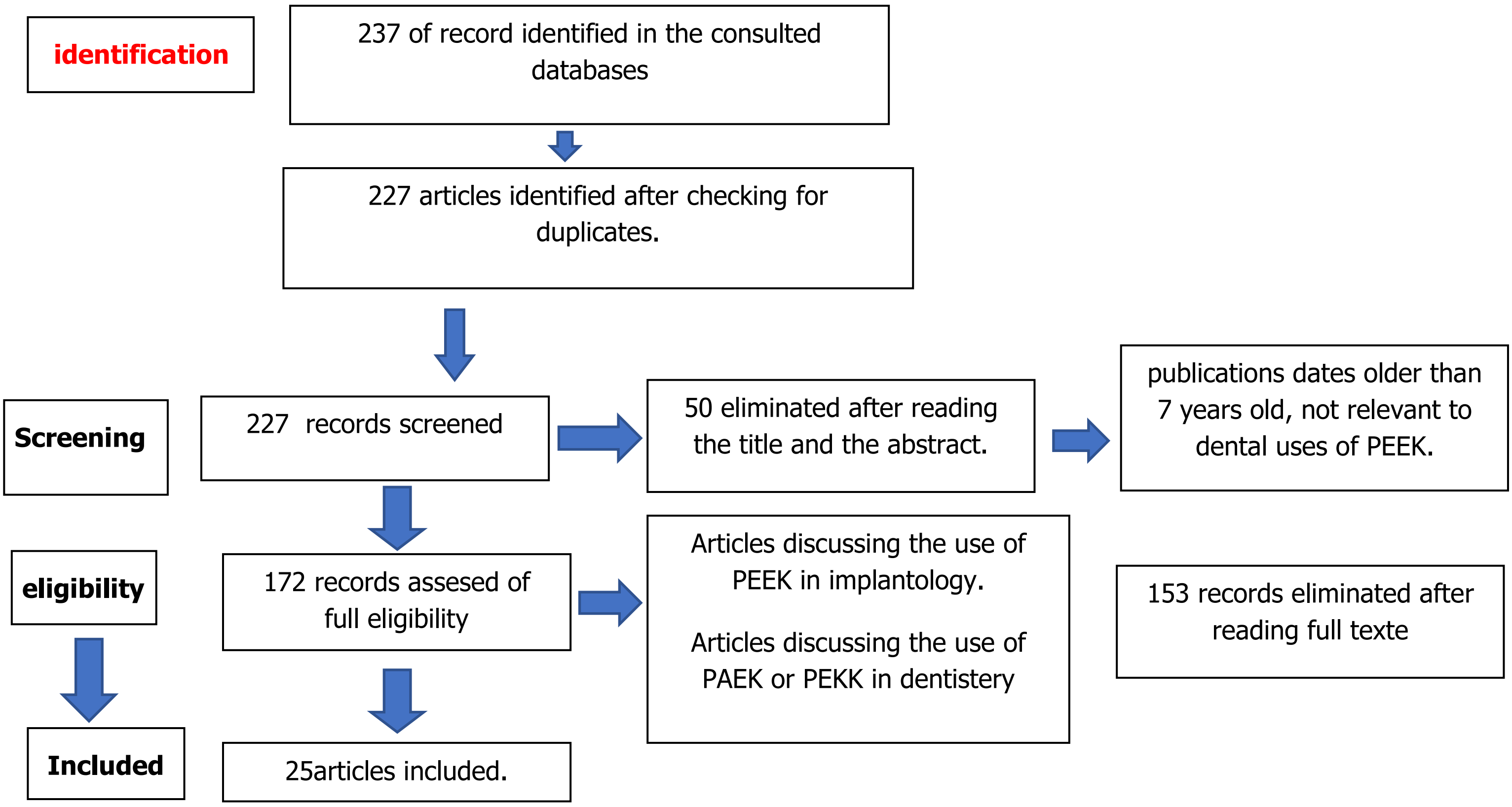


Figure 1: The figure presents the organizational Chart of the Selection of Articles for the Systematic Review.

3. RESULTS

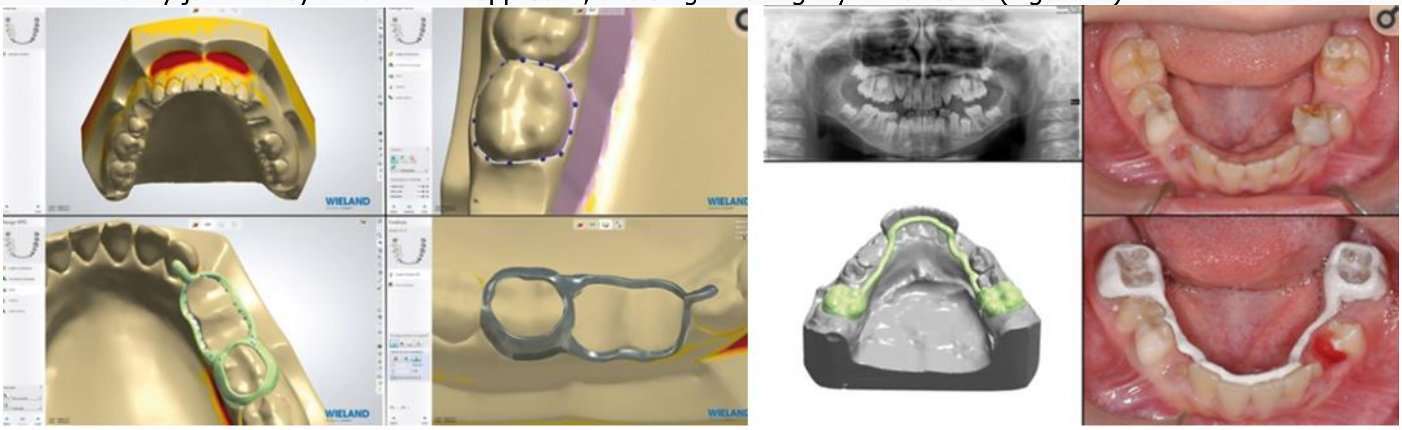
227 articles were found in the database with the following keywords: PEEK, prosthodontics, orthodontics, pedodontics, dentistry. Studies over 7 years old were not included. 50 studies included reading titles and abstracts. 19 full-text articles were selected and used in this review. The selected studies were divided into groups depending on the use of PEEK in dentistry: pedodontics and orthodontics, fixed, removable and maxillofacial prosthodontics.

4. DISCUSSION

4.1. Pedodontics and Orthodontics uses of PEEK

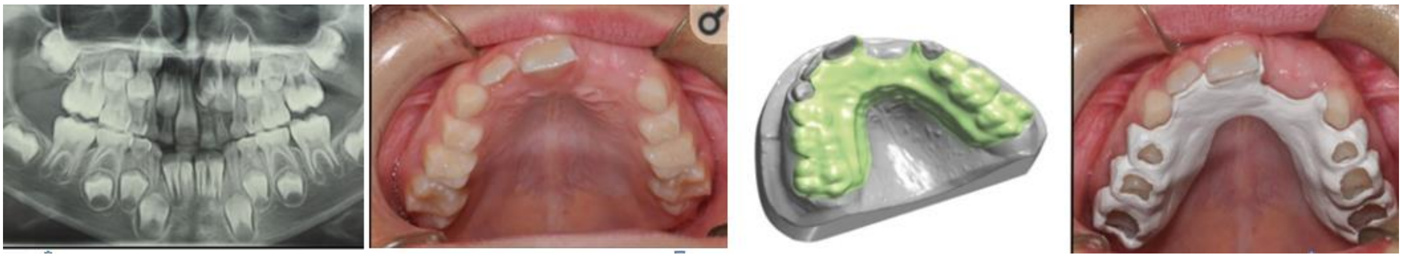
A study in the service of Pedodontics at the Department of Oral and Maxillofacial Sciences of Rome's "Sapienza" University began with the enrollment of patients aged 8 to 10 who needed space maintainers because of premature tooth loss caused by decay or extraction or requiring interceptive treatment because of the existence of a supernumerary tooth or abnormal inclination of permanent teeth. G.Lerardo's team made three prototypes of orthodontic appliances: the lingual arch, the loop band, and the removable plate. The purpose of these devices was to gain space in the oral cavity of the children during the phase of mixed dentition thus facilitating the transition from deciduous to permanent teeth, whether in patients with decayed teeth or in patients undergoing driven extractions for

orthodontic purposes. The workflow started with the production of conventional primary impressions, which were then scanned {3shape in Denmark}. The resulting STL files allowed the digital fabrication of the desired devices which were then printed by a Roland 5-axis milling machine. DWX-50 ", this allowed the obtaining of interceptive devices in PEEK with the 1.3 mm thickness; the following figure shows the 3 clinical cases performed in this study [4].
In 2016, Andrikopoulou and his team also published the presentation of a bonded bridge realized in PEEK in a 14-year-old child with agenesis of the right lateral upper incisor and the left upper canine [5]. In this case, the use of PEEK is mainly justified by his aesthetic approach, avoiding an unsightly metal band (Figure 2).



The first clinical case of lingual arch made of PEEK

The 2nd clinical case of the fixed maxillary space maintainer made of PEEK



The third clinical case of removable maxillary space maintainer made of PEEK

Figure 2: images reporting the clinical cases of the manufactured interceptive pedodontic equipments made in PEEK [4]

PEEK can be used as an aesthetic orthodontic wire. Compared to other polymers, such as polyethylene sulfone (PES) and polyvinyl difluoride (PVDF), PEEK orthodontic wires offer higher orthodontic resistance. Similar orthodontic forces are obtained in comparison with titanium-molybdenum (Ti-Mo) and nickel-titanium (Ni-Ti) yarns [6].

Figure 3: Table comparing the relative properties of different polymers [6].

	Esthetics	Bending strength	Creep resistance	Water absorption resistance
PEEK	+	+++	++	+++
PES	++	++	+	–
PVDF	+++	+	+	+++

4.2 Fixed prosthesis

PEEK appears to be a suitable material for dental applications on the basis of its mechanical properties. However, adequate bonding between PEEK and coating resins remains a key factor in ensuring sustainable survival and success rates. Following this reflection, a study was carried out at the University of Munich where Seven hundred and fifty PEEK veneer samples were manufactured and divided into three pretreatment groups: sulfuric acid etching for 60 seconds, acid etching piranha for 30 seconds and a control group. After pretreatment, surface free energy was determined using contact angle measurements and surface roughness with a profilometer. The topography of pretreated PEEK surfaces was examined using a scanning electron microscope. The remaining samples were packaged with visio.link or Signum PEEK Bond or were not treated as a control group. Half of each group was plated with Sinfony or VITA VM LC and the surface tension of the substrate was measured after storage with undistilled water at 37 ° C for 24 hours to 60 days. The data were analyzed by 4-way and 1-way ANOVA, followed by the « Scheffepost » test and the « chi-square » test (a5.05). Sulfuric acid-treated PEEK samples gave higher surface free energy and surface roughness than piranha acid-etched or untreated specimens. Conditioning with visio.link or Signum PEEK Bond significantly increased surface tension of the substrate, while the Sinfony treated group showed significantly higher values than those with VITA VM LC.

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The present study evaluated the influence of the chemical surface of the pre-treatment of PEEK with different acids in combination with adhesive systems, suggesting a potential promotion of adhesion between the PEEK substrate and the composite coating resins. The results showed that surface treatment of PEEK increased surface free energy and surface roughness; the binding force to a coating resin [7].

In order to study the influence of the variation of the finishing line on their retention, fourteen high-performance polymer dental facets (PEEK) were developed using computer-aided design (CAD) software, then milled using a computer-assisted machine (CAM). They were divided into two experimental groups: seven conventional facets with a linear marginal contour and seven dental facets with the proposed new sinusoidal marginal design. All samples were bound to polymeric blocks whose buccal surface had been specifically prepared for each group. The values of retention and adhesive forces were tested in vitro by applying bending forces on the incisal edge of the facets in a buccolingual direction. The study demonstrated a 50% increase in the values of these forces for the innovative design compared to the conventional design [8].

PEEK veneers having a thickness of 0.1 and 2 mm were synthesized on Ti6Al4V substrates by hot pressing. The influence of PEEK thicknesses on the friction and wear behavior of PEEK structures at Ti6Al4V was investigated under reciprocal slip conditions against an alumina control body immersed in artificial saliva at 37 ° C. In addition, numerical simulations were performed to evaluate the influence of PEEK thickness on the contact stress. The results revealed that friction efficiency and wear rate increased with decreasing PEEK thickness. It was revealed that the elastic properties of the Ti6Al4V substrate affected the thinner PEEK facets that corroborated the friction and wear results. For dental applications, the thickness of PEEK at a critical value of approximately 0.2 mm must be avoided in order to preserve their friction and wear properties [9].

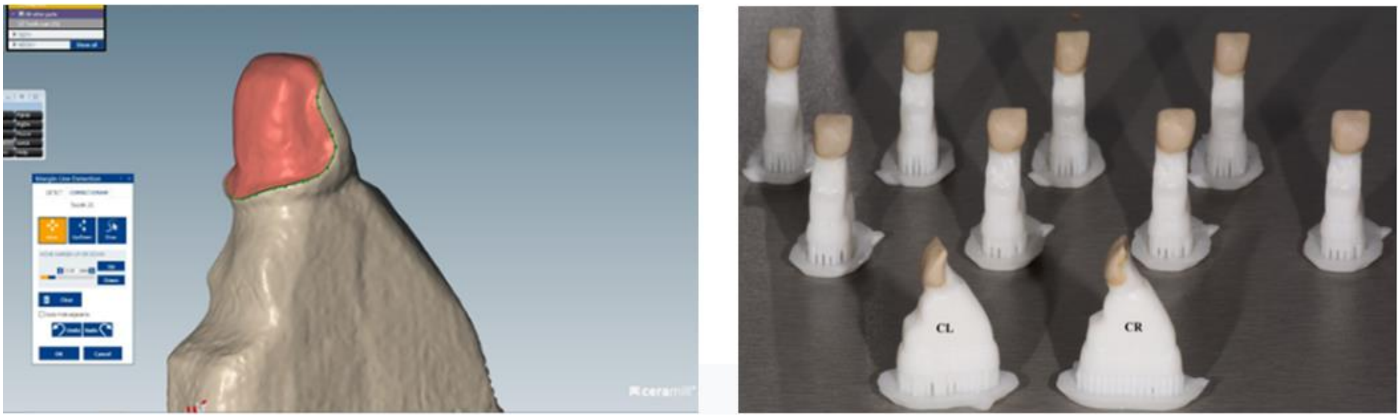


Figure 4: computer-aided design and fabrication of PEEK veneers [8].

In 2016, Zoidis and Papathanasiou published a case on the clinical use of PEEK for the realization of a bonded bridge as a temporal prosthesis after the placement of 2 implants [10]. The team justifies this choice of material by the biomechanical and aesthetic properties provided by the PEEK thus making it possible to limit the risks of prosthetic detachment thanks to a modulus of elasticity that is much lower than the materials conventionally used, thus reducing the stress exerted on the patient. gluing interface. Indeed, in vitro studies have demonstrated better durability of bonded bridges in the case of the use of less rigid materials [11]. In addition, PEEK demonstrated excellent stickiness in vitro tests. Finally, the white color of the PEEK allows the realization of aesthetic prosthetic infrastructure without having to worry about the visibility of a metal band.

Figure 5: Creation of a temporary bonded PEEK bridge [10].

PEEK has also found an application in the realization of endo-crown. Zoidis et al.report indeed the publication of a case where the PEEK is used as reinforcement for the realization of an endo-crown. [12] The use of PEEK is justified by the authors for its mechanical properties to lighten and distribute the masticatory stresses on an already weakened tooth.

Figure 6 : Realization of a PEEK endo-crown [12].

The Indian team of the prosthesis department attached to the "Siri Sai" university in "Telangana" was also able to perform two bridges (maxillary and mandibular) in the same patient victim of a road accident, Les followed by 2, 3 and 6 months of the patient showed a very low plaque accumulation and a healthy gingiva around the teeth, which highlighted the biocompatible nature of the material. Experience of using PEEK as a framework for FPD has yielded very satisfactory results with a high degree of comfort and patient acceptability due to its mild nature [13].

Figure 7 : Realization of two dental-supported bridges from PEEK [13].

Parmigiani-Izquierdo et al. Report a case of implant-supported bridge (PEEK reinforcement) on Zirconia implants with a satisfactory clinical follow-up at 12 months [13].

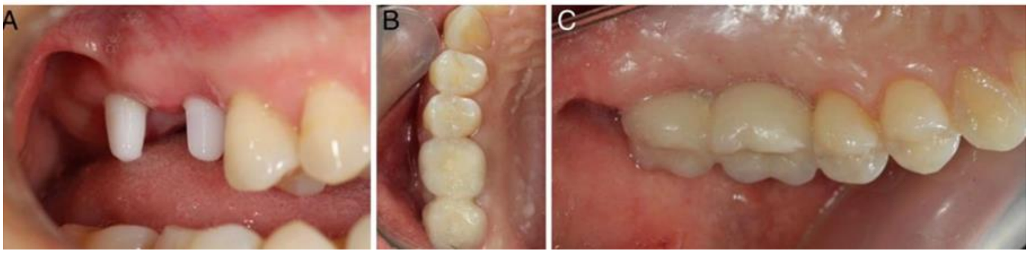
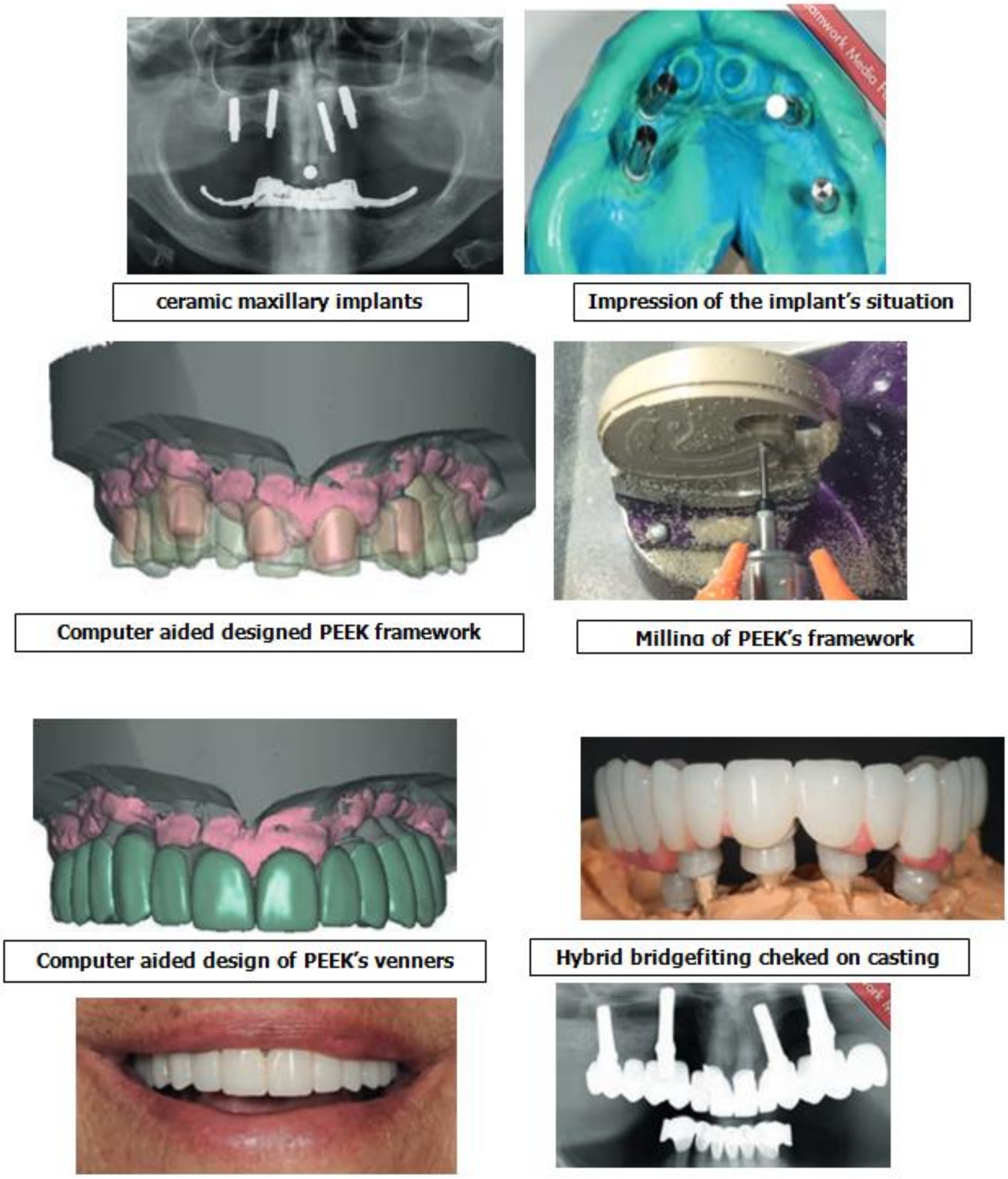


Figure 8 : PEEK bridge fixed on two zirconia implants [14].

Siewert (Add year of publication) [14] realized a hybrid bridge (tooth and implant-supported) of 12 PEEK elements, the dental abutments are the two maxillary central incisors which are connected via a PEEK bridge framework 4 ceramic monoblock side implants (Pure Ceramic; Straumann, Basel, Switzerland) because of the patient's intolerance to titanium, then the bridge frame was designed by computer and manufactured by milling a PEEK disk, subsequently, the cosmetic part of the bridge also designed by computer was made by a highly translucent zirconia to increase the aesthetic rendering of the restoration in the form of veneers.



Patiente's smile after final sealing **Final post-fixation X-ray of the bridge showing its good fiting.**

Figure 9 : steps of realization of hybrid bridge with PEEK's framework [14].

A study of 71 fixed elements (dental and implant-worn), aimed at comparing the mechanical properties of "Trinia" with "BioHPP" concluded that the two polymers have good elastic properties with no significant difference between them; In addition, reinforced polymers, because of their resilience, elasticity and ultralight biocompatibility, are a more effective, aesthetic and economical alternative to molded or milled metal structures in zirconia or titanium discs [15]. Thanks to this elasticity, the prosthesis department at the University of "Cairo" was able to create a mandibular implant-supported bridge designed and manufactured digitally according to the concept "All-on-four" with PEEK framework on which, composite veneers have been added to improve the resilience as well as the aesthetic rendering of the prosthetic restoration, the following figure traces the treatment plan followed in this clinical case [16].

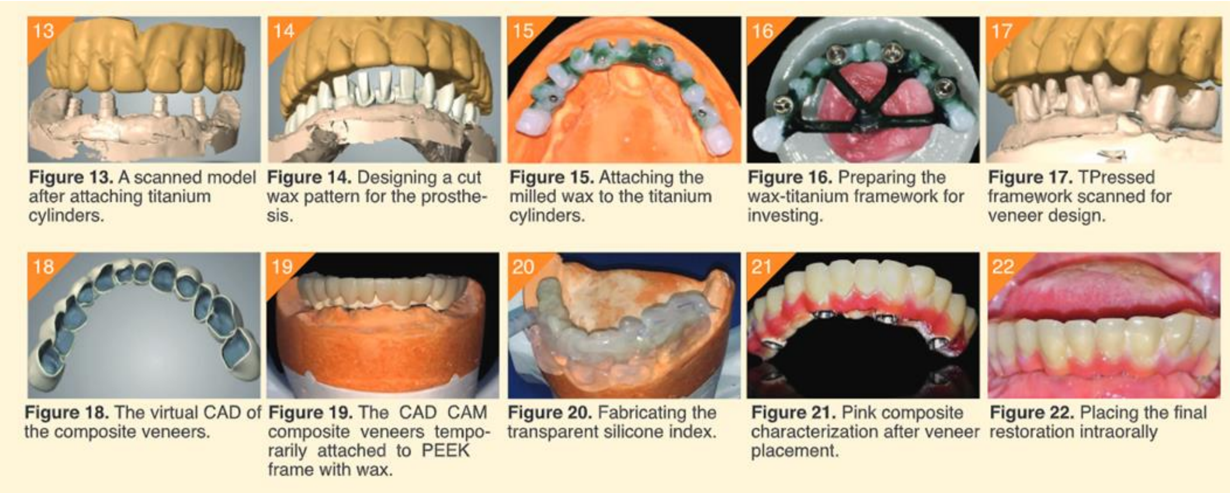


Figure 13. A scanned model after attaching titanium cylinders.
Figure 14. Designing a cut wax pattern for the prosthesis.
Figure 15. Attaching the milled wax to the titanium cylinders.
Figure 16. Preparing the wax-titanium framework for investing.
Figure 17. TPressed framework scanned for veneer design.
Figure 18. The virtual CAD of the composite veneers.
Figure 19. The CAD CAM composite veneers temporarily attached to PEEK frame with wax.
Figure 20. Fabricating the transparent silicone index.
Figure 21. Pink composite characterization after veneer placement.
Figure 22. Placing the final restoration intraorally

Figure 10 : « All-on-four » Implant-supported bridge with PEEK framework and composite veneers [16].

3.Uses of PEEK in maxillofacial prosthesis

Thanks to its biocompatibility and its lightweight, the PEEK could be used as a maxillofacial prosthesis obturator, Costa-Paulau [17] reports a clinical case where, in front of a loss of Centro-maxillary substance with sinus communication, a hollow shutter (0.5mm thick) could be designed numerically and machined via a 5-axis milling machine, the PEEK's lack of adhesion to the resin could be bypassed by the creation of a retention box in the shutter followed by microabrasion by silica particles, the appointments confirm the good maturation of peri-prosthetic soft tissue, the patient reports comfort due to the lightness of the material

Figure 11: maxillary obturator designed in PEEK [17].

4. Uses of the PEEK in partial dentures

Galvanic corrosion and low aesthetic rendering are problems related to the use of metal dental claps, these problems are overcome by the use of PEEK claps, Ichikawa [18] used these in the design of a mandibular partial denture in a patient aged 84 years, 2 years after its insertion, except for a slight change in their color, the claps have maintained their retention and stability, the patient reports masticatory comfort and efficient retention of the prosthesis.

Figure 12 : claps made from PEEK [18].

The low weight and the absence of allergy are assets boasting the merits of using PEEK (BioHp) as an alternative to chromium-cobalt in the realization of partial denture, Zoidis [18] has carried out in the same patient a PAPC in chromium -cobalt and a second PEEK, the weight of the latter is 27.5% smaller than that of the first, even if the configuration is modified (cobalt chrome lingual bar against a lingual PEEK headband), Zalatric [19] stresses that PEEK partial dentures compared to acetal ones require a biomechanically balanced design to ensure periodontal durability.

Figure 13 : comparison of the weight of two partial dentures in PEEK and that in cobalt-chromium [19].

Pickart [20] also compared the weight of PEEK frames of partial dentures with those made of chrome-cobalt and poly-methyl-methacrylate (PMMA), the weights are respectively 6.8 g (cobalt-chromium), 1 g (PEEK) and 0.8 g (PMMA) {Fig 15}.

Figure 14 : comparison of the weight of three mandibular frames: chrome-cobalt, PMMA and PEEK [20].

A randomized clinical trial conducted by Maryod (2019) studying the condition of the claps support teeth in case of bilateral free edentulism, in 24 patients divided into two groups, the first having been paired with cobalt-based partial prosthesis and the second one with PEEK ones (juvora) all obtained by milling from a digitized design [21]. The results show that the condition of the supporting teeth (gingival index, presence of periodontal pockets and bone height) of claps contained in PEEK's partial dentures is better than those designed in cobalt chrome.

Figure 15: table comparing the mechanical and physical properties of PEEK with cobalt-chromium-molybdenum, titanium, and acetal.

	Cobalt-chromium-molybdenum [22]	**Titanium** [23]	**Acetal** [24]	**PEEK** [25,26]
Elastic limit (MPa)	460-640	830	63	110
Breakage limit (MPa)	520-820	900	68	180
Elasticity module *(GPa)*	145-220	110	290	4
Elongation *(%)*	6-15	10	25	20
Hardness *(Vickers)*	330-465	970	38	80
Coefficient of thermal expansion (CET)	13 à 15	20	80	5.4
Merge intervals (°C)	1250 - 1500	1650-1675	170-175	340-387
Casting temperature(°C)	1300 - 1600	1609-1660	162-170	343
Density (g/cm3)	8.3	4.3	1.41	1.3

5. CONCLUSION

Thanks to its biocompatibility, its high mechanical properties, and its lightweight PEEK remains an adequate material both in orthopedics, in the restoration of bone loss, in orthodontics as a substitute for metallic threads, in fixed prosthodontics instead of traditional frameworks, and in removable prosthodontics instead of cobalt-chromium.

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