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PEEK Retainers without CAD-CAM: Simple Solutions for Everyday Challenges

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Abstract: Background: The need to perform occasional or continuous MRI exams and the interference with metal orthodontic appliances might be important and take a primary role during retention since the retention period is significantly longer than orthodontic treatment. Several non-metallic materials were proposed as potential alternatives to perform fixed retainers in orthodontics, but they showed internal limits. Methods: Polyetheretherketone (PEEK) was used in the present clinical report as a fixed orthodontic retainer in the lower arch in order to perform an appliance with mechanical properties comparable to metallic ones but with a higher biocompatibility material and without the need for removal in case of an MRI exam. The retainer wire was handmade in the studio and then shaped to fit the arch. Results: PEEK showed a good capability for constructing a lingual fixed retainer compared to other aesthetic non-metallic and metallic materials. Conclusions: To the best of our knowledge, this study proposes how to easily build a retainer in PEEK and provides a clinical example of how this material can be beneficial.

Keywords: PEEK; orthodontic retainer; orthodontic appliances; MRI; 3D printing

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1. Introduction

Orthodontic retention is important for maintaining post-treatment outcomes, as it prevents teeth from returning to their original positions and opposes the natural tendency of teeth to shift towards the centre.

The traditional clinical approach in orthodontic retention provides for a fixed orthodontic retainer, which should have some ideal characteristics related to mechanical properties and biocompatibility [1]. Also, the adhesion properties are fairly good as currently metal detachments became infrequent, thanks to the adhesive systems currently in use, ensuring reliable retention of orthodontic appliances. Metal alloys are usually employed [1–3] for this purpose since they show excellent elastic properties [4].

Usually, a stainless-steel braided wire is chosen and placed on the lingual surface of the inferior teeth between the two canines. The positioning of this wire is a very delicate procedure, as it must be shaped to adhere closely to the lingual surfaces of the teeth, ensuring it is passive and does not apply forces that could cause tooth movement [5].

Unfortunately, all metal alloys have recently generated issues due to aesthetics and complications such as metal allergies since several of the employed wires release considerable amounts of Nickel (Ni), exposure to which may have biological implications [6]. Ni has been suggested to be a potent allergen that induces an immune response, and it is present in orthodontic appliances, especially wires. Mechanical and chemical injuries in the oral environment cause the release of Ni from the appliance, and this effect might be enhanced in orthodontic fixed retainers that remain in the oral cavity for long periods.

Unfortunately, mechanical loading and changes in pH have been suggested to stimulate Ni release from conventional and manganese–steel "Ni-free" wires, then prevents the use of these wires for long intervals due to their possible biological implications [7,8].

Moreover, currently, demand for non-metallic orthodontic materials has increased because they interfered with magnetic resonance imaging (MRI) [9–11]. The need to perform occasional or continuous MRI exams and the interference with metal orthodontic appliances might be important but of a secondary role during orthodontic treatment since the latter is performed for a limited time. Nevertheless, this aspect becomes relevant and takes on a primary role during retention since the retention period is significantly longer than the orthodontic treatment itself. Recent evidence has recommended the removal of metal fixed orthodontic retainers when MRI needs to be performed due to the artefacts that might affect diagnosis, especially with the recently increased power of the magnetic field of the new generation MRI machines such as 3T and 5T [12]. The previously discussed reasons have encouraged clinicians and researchers to investigate non-metallic materials in orthodontics, especially fixed retention. However, non-metal alternatives to orthodontic wires for fixed retainers should have comparable properties to metal wires in mechanical behaviour, strength, resistance, ductility and adhesion properties, and biocompatibility. Several materials have been proposed, and the lack of ideal characteristics prevented their spread and use in clinical routines.

Several non-metallic materials have been proposed as a potential alternatives for fixed retainers in orthodontics [13], such as glass fibre-reinforced plastic (GFRP).

The fibres, usually glass, carbon, or polyamide, are completely submerged in a resin layer. These materials have demonstrated high flexural strength and good aesthetic properties, as their colour closely matches the natural colour of teeth [14].

Unfortunately, they also exhibited considerable bending and distortion that causes the disruption of the fibre–polymer interface and decreases their mechanical properties [15,16]. Moreover, GFRP has shown significantly lower bond strengths when compared to conventional stainless-steel wires, which may result in higher bond failure, regardless of the bonding procedure [17]. The biocompatibility of GFRP is still also questionable since it is not recommended in patients at high risk of dental caries related to the cytotoxicity exhibited by human oral fibroblasts [18] and, according to recent findings, it has been shown to significantly reduced cell viability and increase DNA damage and oxidative stress production in human epithelial cells [19].

Other non-metallic materials have been investigated and among them polyphenylene polymers have been developed into transparent orthodontic wires that can deliver forces equivalent to the beta-titanium and Ni-Ti wires commonly used in orthodontic practice [20–22].

Unfortunately, currently, the lack of materials completely comparable with metals in fixed orthodontic retention prevents clinicians from completely avoiding metal fixed retainers, which are still largely used in clinical practice. In recent years, plastic materials have been developed in other fields of medicine to provide good mechanical and thermal properties. They are known as 'super engineering plastics' (SEPs), which might have several ideal characteristics for their application in general dentistry and orthodontics. Among these SEPs, polyetheretherketone (PEEK) is a synthetic, tooth-coloured polymeric semicrystalline material that has been used in orthopaedics and maxillofacial surgery as a bone substitute for many years [23]. It has good strength properties combined with a lower Young's modulus of 3–4 GPa, like human bone, which makes it a sensational material. In addition, this material might also be modified by incorporating other materials, such as carbon fibres, that might increase the elastic modulus up to 18 GPa [21,23]. Its flexibility modulus ranges from 140 to 170 MPa, a value very close to enamel and dentin. These characteristics and its considerable resistance and resilience make this material suitable for supporting the normal forces developing in the oral cavity during swallowing, chewing, and phonation [24].

Moreover, it can be easily sterilised since it has been revealed to be resistant to thermal (melting above 300 °C), mechanical, and chemical attacks. In addition to being sterilizable, the smooth surface of this material retains less plaque, with an index equal to or lower than that of zirconia [25]. This property facilitates easier cleaning for the patient, thereby reducing the risk of periodontal problems.

SEPs, particularly PEEK, offer improved aesthetics compared to metal retainers due to their colour closely matching that of natural teeth. Moreover, these materials are not completely opaque and can reveal the underlying dental matrix, allowing them to integrate harmoniously with dental structures.

These materials are also highly biocompatible, making them an excellent alternative for patients allergic to nickel, which is commonly released into the oral cavity from traditional metal retainers [26].

Like other SEPs, it might be available in different shapes and sizes for different purposes, and it might be used directly from the manufactory or employed in milling machines and 3D printing processes. One of its uses is to provide a range of high-technology tubing for angioplasty shafts and inner members, vascular and endoscopic catheters, chemotherapy, and drug delivery tubing because of its high biocompatibility. The possibility of independently designing the required shape makes it possible to have custom-made devices for each patient. This feature is precious for retainers because achieving precise passivity is crucial for maintaining the stability of the orthodontic result and ensuring patient comfort.

PEEK was recently proposed in general dental practice [27] for its excellent mechanical properties with application in prosthodontics [28] and orthodontic aesthetic and metal-free wires [21,24,25]. Maekawa et al. [15] compared PEEK wires to other polymers and traditional orthodontic wires, such as cobalt–chromium (Co-Cr), titanium—-molybdenum (Ti-Mo), and nickel–titanium (Ni-Ti), and concluded that PEEK has the optimal characteristics to be used as an aesthetic metal-free orthodontic wire. Its properties also suggest possible application in orthodontic retention to avoid the issues related to metal allergies and MRI previously discussed, with the improvement of mechanical behaviour compared to GFRPs and other SEPs.

In the proposed case, PEEK was used for the first time as a fixed orthodontic retainer in the lower arch in order to perform an appliance with mechanical properties comparable to the metallic one, but with higher biocompatibility material and without the need for removal in the case of an MRI exam The presented patient needed a fixed retainer for periodontal reasons but was subjected to MRI exams every six months for general health reasons; therefore, a metal-free retainer was mandatory.

2. Materials and Methods

The patient selected was a 53-year-old female who presented a significant crowding in the fifth sextant (Figure 1a–c).

After completing orthodontic therapy, it was crucial to maintain the achieved results while minimising the risk of relapse. In addition to its orthodontic function, the retainer was also necessary for periodontal reasons. The treatment plan provided the extraction of the right lower central incisor for periodontal and endodontic problems and intrusion of the lower incisors [2].

The teeth were then aligned with a straight wire appliance, but metal-free fixed retention was mandatory at the end of fixed orthodontic treatment since the patient had to perform MRI exams once a year as follow-up for cancer healing monitoring [29].

After evaluating the alternatives, it was decided to fabricate a PEEK retainer. This material was chosen due to its lower plaque retention and ability to not interfere with MRI.

PEEK wire 0.5 mm thick for a fixed retainer was obtained from a PEEK dental disc 16 mm thick (PEEK-OPTIMA™ polymer from Invibio Biomaterial Solutions, JUVORA™, Lancashire, UK) using a milling machine (Dental Machine G5, Bobbio, PC, Italy) (Figure 2).

The measure of 0.5 mm was chosen to reflect the size of the multibraided wire (0.0195) generally used as a retainer.

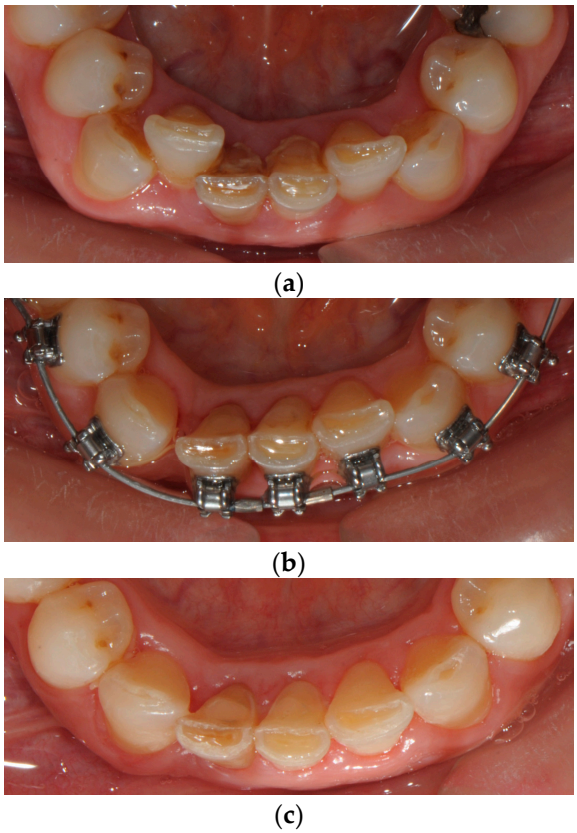


Figure 1. Aligning and finishing case. (**a**) Initial photo, (**b**) photos during therapy, and (**c**) photo at end of therapy.

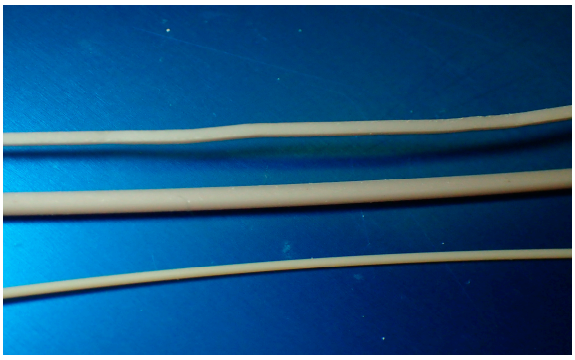


Figure 2. PEEK wires of different thicknesses. PEEK wires of the desired thickness may be obtained from a milling machine.

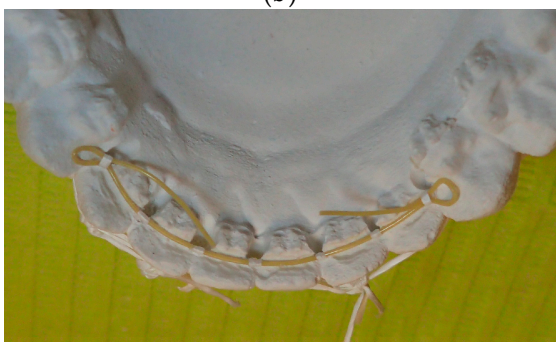
In the future, to make the workflow easier, spools of PEEK filaments can be an end product or made using a wire drawing machine starting from certificated PEEK fibres (Novus Life Science—Hong Kong).

The PEEK wire is flexible and easy to form, which allows it to be adapted to the lingual surface of the teeth on the dental cast. The PEEK wire of the desired length might be adapted to the lingual surface of lower incisors and canines in the dental calk obtained from the alginate impressions. Once the wire is obtained from the milling machine, holes are perforated on the dental cast to adapt the PEEK wire to the teeth surfaces using ligatures (metallic ligatures or floss or PEEK ligatures) (Figure 3a–c) since the wire is very flexible at room temperature. Ensuring that the wire is carefully shaped to be passive is essential

to avoid any unwanted forces that could cause misalignment of the dental elements. Properly adapting the wire to the arch shape is also important to prevent excessive plaque accumulation at the material–enamel interface and to facilitate effective oral hygiene practices. These considerations are the key to maintaining the patient's orthodontic and periodontal health.

(**a**)

(**b**)



(**c**)

Figure 3. Adapting the PEEK retainer on the dental cast. First, holes are perforated on the dental cast to accommodate the ligatures constraining the PEEK wire (**a**,**b**). Once the PEEK retainer is in situ, the ligatures adjust the shape (**c**). Then, the thermal processes are performed.

PEEK is sensitive to high temperatures, and according to different temperature ranges and different manufacturers, the shape might be changed permanently, similarly to NiTi orthodontic arch wires [30]. Once the retainer is modelled, the wire within the dental cast undergoes heating processes in a ceramic dental oven with the following sequence as advised by the manufacturer: 150 °C for 60 min, 200 °C for 60 min, 150 °C for 30 min, and cooling until the room temperature. This heating process allows the wire to stabilise the desired shape by changing its microstructure. This step can be carried out without problems because this material has a melting point greater than 300 °C, so the model retainer will not change in shape but will only stabilise the result created.

The PEEK retainer was then subjected to sterilisation processes in the dental autoclave.

Polyvinylsiloxane was then used to build a reliable semirigid transfer template to have the correct position of the wire on the teeth once it was accommodated in the mouth (Figure 4). Due to the fabrication of this semi-rigid template, the retainer will be positioned in the oral cavity with precise accuracy as determined. This approach helps to eliminate positional errors ascribable to human factors [31].

Figure 4. PEEK retainer adapted on the plaster model and the transfer guide.

3. Results

Once the retainer was built, the placement and bonding procedure did not differ from the placement of a conventional metallic fixed retainer and comprised the following steps:

The teeth were prepared for receiving the adhesion by placing of the dental dam (Figure 5).

Figure 5. Placement of the dental dam.

The lingual tooth surfaces to be bonded were first pumiced using a fluoride-free paste.

After carefully drying the lingual surfaces, the PEEK retainer was tried to ensure the correct accommodation and matching.

After testing the correct accommodation of the retainer, it was removed, and the enamel surfaces were etched with 37% phosphoric acid (Total Etch Gel—Ivoclar—Vivadent. Zurich, Switzerland) for 60 s, then rinsed for two minutes and air-dried.

The light-cured adhesive was then applied to the lingual surfaces.

The retainer was placed using the template and was fixed by a thin layer of light-cured flowable composite (Transbond™ LR Adhesive IFU, 3M Unitek. Orthodontic Products. Monrovia, CA, USA) [31] (Figure 6).

Figure 6. Placement of the template and fixation of the retainer with flowable composite.

The template was removed, and the fixed retainer was checked for any flowable composite addition (Figure 7).

Figure 7. Checking the retainer after the removal of the template.

The retainer was checked for common oral hygiene procedures (Figure 8).

Figure 8. Checking for common oral hygiene procedures. Even though PEEK is not a metal, it has similar mechanical properties at similar thicknesses, simplifying common oral hygiene procedures compared to other non-metallic materials needing higher thickness [32].

Finally, the dental dam was removed (Figure 9).

Figure 9. PEEK fixed the retainer after removal of the dental dam and at the end of the bonding procedure.

The retainer fits perfectly and passively to the lingual surface of the lower teeth.

4. Discussion

Currently, few studies have evaluated the efficiency of PEEK as a retainer material. According to the authors, PEEK represents a viable and alternative material in dentistry due to its biocompatibility, resistance to chemical and thermal agents, low plaque affinity, and good flexibility. Compared to other non-metallic and metallic aesthetic materials, PEEK has demonstrated good potential for creating customised fixed orthodontic retainers in these cases. The bonding procedure is consistent with traditional methods used for metal fixed retainers and is straightforward to perform. Since there are no differences in the bonding process compared to traditional metal retainers, no new adhesive materials or specialised expertise are required. Only the essential areas of the enamel are bonded, making the potential damage to the enamel similar that of conventional retainers. However, given that the PEEK has the same colour as teeth, the debonding process needs to be performed under magnification.

As highlighted by Beretta [21,33], PEEK is suitable for creating CAD-CAM retainer wires with the benefit of not causing interference during MRI scans or inducing allergies. Furthermore, Beretta emphasises the facility of reprinting or fabricating a new custom retainer in case of breakage or re-bonding a detached wire even years later.

Other studies, such as that by Kadhum et al. [26], report that the effectiveness of a PEEK retainer with a diameter of 0.8 mm is comparable to that of metal wires, especially if the PEEK wire is pre-treated with air abrasion. The analysis of Win et al. [27] also notes that an SS 0.036 retainer is stronger than a PEEK retainer. However, PEEK wires (1 mm $\times$ 1.5 mm) were found to be less deformable under oral forces such as tongue pressure, which is important because less deformation ensures greater stability.

Additionally, the authors believe that adapting the wire on the dental cast and shaping it with heat treatment allows to have a precise positioning and reduces chair time. This approach ensures the wire remains passive, avoiding any retainer-related pathologies.

However, as highlighted in our latest in vivo research [34], PEEK retainers are subject to adhesion problems. Therefore, it is recommended to monitor the patient as long-term follow-up has not been thoroughly investigated.

The authors also suggest using this material only in those who must undergo MRI or have periodontal problems, for which PEEK represents a good solution.

Further research is required to fully explore and enhance PEEK's potential applications in orthodontics and highlight its related problems.

5. Conclusions

According to the case presented, PEEK (polyether ether ketone) is an innovative material which has the potential to revolutionise clinical practice.

PEEK demonstrates a unique combination of mechanical and chemical properties, making it particularly suitable for medical applications. This material is characterised by high mechanical strength, rendering it durable and capable of withstanding substantial loads. Furthermore, PEEK exhibits high resistance to chemicals and corrosion, ensuring longevity even in aggressive biological environments. It is also resistant to high tempera-

tures, thus allowing for sterilisation, and exhibits minimal plaque retention. Also, PEEK does not cause adverse reactions in human tissues, thereby mitigating issues related to biological compatibility. Its inherent colouration, which can be modified to resemble the natural colour of teeth, provides significant aesthetic advantages over traditional metallic materials. Another important feature of PEEK is its compatibility with MRI exams, enabling visualisation during orthodontic retention without interference.

In the present case study, the retainer was handmade. However, today it may not even be necessary to produce the PEEK wire directly, but it is possible to buy it produced by extrusion of a 3D printing filament.

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Data Availability Statement: The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

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Conflicts of Interest: Authors Lea Siani and Rosamaria Fastuca were employed by the company Private Practice. The remaining authors declare that the re-search was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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