

PEEK surface modification methods and effect of the laser method on surface properties

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ABSTRACT

Polyether ether ketone (PEEK) is one the most interesting polymeric materials used in the industry today, such as aerospace, nuclear reactors, polymer electrolyte membranes and especially in biomedical applications like bone implants. PEEK's desirable properties like mechanical strength, biocompatibility, chemical resistance, radiation resistance and high thermal stability in the body make this suitable polymer choice for a bone implant. Besides these useful properties, PEEK is bio-inert in the biological environment, which is a big problem in implant application. Fortunately, there are several methods to improve the surface bioactivity of such materials. Here surface modification methods of the PEEK, including laser and their effect on the surface bioactivity were studied. Laser techniques are one of the exciting methods for PEEK surface modification because of being a secure processing method, time-consuming, easy to control the laser parameter, which leads to the control of surface properties. Several kinds of laser with different settings is used for the enhancement of the surface of PEEK, were described here. Here different surface modification techniques to enhance the adhesion and wettability of the PEEK surface studied. Along with varying categories of laser were introduced and different laser methods, which used for PEEK surface treatment is collected, that is the exciting point of this review paper.

Keywords: Polyether ether ketone (PEEK); Laser; Surface modification; Biocompatibility.

1. INTRODUCTION

Bone and joint-related diseases, like vertebral degradation, bone fracture, tumor, tuberculosis, and arthritis pulse aging-related bone degradation and bone injuries, caused by accident, increase the inquiry of artificial bone replacement to restore bone function and structure [1]. Orthopedic implants, which are used to restore the bone function in implant surgery, are divided into three main categories, including 1. Metal and Metal alloy, 2. Ceramic, and 3. Polymer. All of these materials have some advantages and disadvantages. Metal bone implants have excellent mechanical strength, friction-resistance and can provide non-toxic effect, but some defects like high elastic modules can cause stress shielding, leading to adsorption of surrounding bone tissue, which finally causes loosening of the implant [2-5]. Further, the radiopacity of metals hinders the ability to track the implant after surgery through imaging technique like computed tomography (CT) images and magnetic resonance imaging (MRI).

Additionally, the long-term presence of metals in the human body can cause allergic tissue reactions, which lead to osteolysis [6, 7]. About the ceramic implants, there are different groups like metal oxides, which are inert, but the bioactive groups like calcium phosphate and glass ceramics are a good choice. This is due to the fact that they can provide non-toxic properties and exhibit the biocompatibility and also resistant to corrosion, but their artifact is low mechanical properties like ductility, small fracture, low toughness, brittleness and high elastic modules which limit their application in load-bearing place [8]. For polymers, there are also some benefits like secure processing, but some limitations like high flexibility and weakness. These causes the materials poor mechanical properties as a bone implant, being sensitive to sterilization processes and they may lead to swelling in the body and leach products, which may have side effects [9, 10].

As mentioned above, there are few choices for polymer as a bone implant because of the low mechanical properties, but today polyether ether ketone (PEEK) become a most interesting polymer in bone implant and medical application because of the having biocompatibility and excellent mechanical properties, which is close to bone tissue [11]. PEEK was used in different biomedical applications, like in vertebral surgery as a material of the interbody fusion cage, joint replacement, bone screws, pins, dental implant and also carbon fiber reinforced PEEK (CF/PEEK), used for fracture fixation and the femoral prosthesis in artificial hip joints [12, 13]. Still, this polymer is bio-inert, which means it shows low bioactivity for cell attachment in the body so it needs some modification methods [14]. Besides a lot of modification methods used for PEEK surface modification [15-17], the Laser method is a favorite technique, which offers a great number of advantages, like possible modification of surface roughness and chemistry in one-step, avoiding the utilization of toxic substances.

This technique keeps the bulk properties intact with the altering of surface properties, modification of the surface at a macro-, micro-, and nano-size scale with a high spatial and temporal resolution. The contamination of the process is easily avoided, offers high processing speed, easy automation, and the possibility to treat large areas by controlling the parameters of the laser process [18]. Therefore, laser technology has been used for surface modifications of materials, especially polymers like ultra-High-Molecular-Weight Polyethylene (UHMWPE) [19-21], polypropylene (PP) [22, 23], Polyethylene (PE)[24, 25], Polycarbonate (PC) [26, 27], polytetrafluoroethylene (PTFE) [28], Polyimide (PI) [29] and PEEK, in some studies [30].

There are significant numbers of research regarding laser parameters like laser wavelengths and pulse duration to evaluate their effect on the surface modification of PEEK. Surface

functionalization of PEEK by a laser has been successfully achieved using laser wavelengths ranging from UV (355 nm) to middle infrared (10.6 μ m) [31-33]. Also, there are several kinds of lasers with different powers that can be used to alter the surface

properties like surface roughness, wettability, functional groups, and finally surface adhesion of PEEK, which is discussed here [32, 34].

2. PEEK

PEEK is a member of the polyaryl ether ketone family, which is a semi-crystalline and thermoplastic with linear polycyclic aromatic structure [35]. This polymer has particular physical and chemical properties because of the chemical composition, which has an aromatic molecular backbone with ketone and ether groups between the aryl rings. These this chemical structure makes the PEEK wear-resistant, thermal resistant, chemical resistant, and easily serializable. However, besides of its biocompatibility, and exhibiting great mechanical property such as close elastic module 8.3 GPa to bone tissue 17.7 GPa, still has a big issue, being its bio-inertness [11, 13, 36, 37]. Very recently, PEEK has been used as an alternative to metallic implants in the orthopedics fields, because of the close elasticity modules to human bone tissue. This property causes load distribution between the implant and bone that forbids the phenomenon of stress shielding after implantation, which makes

PEEK a good choice for bone implant substitutes like a skull, dental implant, and dental implant materials as a superstructure, implant abutment, fixed crowns, fixed bridge, jaw or implant body in comparison with metal implant [36, 38]. On the other hand, the defect of this polymer is the bio inertness, which causes neither protein absorption nor promotes cell adhesion that led to weak tissue adhesion and surrounding bonding [36, 39, 40]. Therefore, to achieve proper cell attachment, it is necessary to look for methods to enhance the bioactivity of this polymer. There are a variety of researches that have done to improve the bioactivity of the PEEK polymer through different ways including, chemical [41], mechanical and physical modification, each of them classified to various methods discussed here. The discussion followed by a laser technique, and the effect of laser on PEEK surface modification is discussed separately.

3. SURFACE MODIFICATIONS METHODS OF PEEK

Surface modifications methods of PEEK.

Surface free energy is such an essential factor for cell adhesion. Through different modification methods, the surface energy of the adherent will change or increases to make bonding. The surface modification, which carries out for PEEK samples is different [15]. There are several methods for surface modification of the PEEK, which investigated in various categories in varieties of studies, but in general, the surface modifications of the PEEK divide into below categories:

Chemical.

First, there are several chemical reactions, which change the surface functional groups and enhance the adhesion of the PEEK surface. However, the condition of this kind of chemical reaction is rigorous and difficult to control, because of the strict time-temperature-pressure conditions; therefore, it is not easy to implement as a solution on an industrial scale. There is some chemical modification, which creates functional groups on the PEEK surface like wet chemistry modification or sulfonating treatment. However, these have rarely used, because of the stable chemical structure of PEEK that makes it hard to change chemical reaction [42]. In addition, coating the PEEK surface [17] via different methods has been performed to create the functional groups on the PEEK surface. These methods include hydroxylated groups (PEEK-OH) obtained by reduction, Carboxyl groups prepared by coupling a diisocyanate reagent to PEEK-OH, Amine groups (PEEK-NH₂) gained by hydrolysis of PEEK-COOH, and amino carboxylate PEEK obtained from the coupling of amino acids to PEEK-COOH [43, 44].

Mechanical surface roughening.

Surface roughening is probably the easiest and the cheapest treatment technique that can be done using silica carbide paper or

sand or grit blasting. Sometimes, with roughness, some adhesive like Epoxy, Acrylics, Cyanoacrylates, Urethanes, Silicones, Anaerobic were used, and the result showed Surface roughening of a PEEK compound in combination with epoxy adhesives resulted in increased bond strengths with values between 9MPa and 30MPa[45, 46].

Surface coating.

There are various bioactive materials, which have been used as a coating on the surface of PEEK, including hydroxyapatite, titanium, gold, titanium dioxide, diamond-like carbon, and tert-butoxides [47, 48]. The most popular one is hydroxyapatite (HA), which is the calcium phosphate-based bioceramic with (chemical formula $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$) and exhibits perfect bioactive properties in the biological environment [49]. There are various methods to improve the surface bioactivity of the PEEK, with the help of bioactive materials coating. Some are cold spray technique, radio-frequency (RF) magnetron sputtering, spin coating techniques, aerosol deposition (AD), ionic plasma deposition (IPD), plasma immersion ion implantation and deposition (PIII&D), electron beam deposition, vacuum plasma spraying (VPS), physical vapor deposition (PVD), and arc ion plating (AIP) [50].

PEEK Composite.

Another approach to make the PEEK surface bioactive is the composite structure. In this method, some bioactive materials which have good adhesion properties as Hydroxyapatite will be used as impregnating materials in the bulk of the PEEK to cover the weakness of the PEEK property and also keep the excellent mechanical properties of the PEEK [51]. Regarding some studies, there are two categories of the composite based on the size of the impregnating bioactive materials: the conventional PEEK

composites and the nano-sized (<100 nm) composite method. The latter is a good one because it just changes some chemical surface property and keeps the other mechanical, electrical, and optical properties intact [52-55].

Plasma modification.

Plasma technology has long been used for polymeric biomaterials [56-58]. One of the most popular and easy handling methods for PEEK surface modification is a plasma spray method, which alters the surface chemistry and sometimes has an effect on the surface roughening. Typical gases, which are used for the treatment of polymers, are air, oxygen, nitrogen, helium, argon, and ammonia. In addition, it has been showed that gas pressure could affect too. Air is always accessible and available, but has little effect; one disadvantage of using a plasma technique could be the low-pressure condition, which requires a chamber for treatment [46]. Briem et al. [59] treated PEEK surface with the plasma process (a microwave plasma in NH_4/Ar and a downstream microwave plasma in H_2/Ar), another group treated PEEK with N_2/O_2 low-pressure plasma to improve the bioactivity of PEEK [17]. The other one treated PEEK with RF plasma with a mixture of CH_4/O_2 gases and also using a plasma immersion ion implantation and deposition (PIII&D) technique with a CH_4/O_2 gas mixture to modify the surface of PEEK [15, 60]. Deposition of oxygen-rich nanofilms on PEEK with high surface energy, greatly improved cell adhesion [60]. Waser-Althaus [61] applied the O_2/Ar or NH_4 plasma to treat the PEEK surface. They demonstrated an increased adhesion, proliferation, and osteogenic differentiation of adipose tissue-derived mesenchymal stem cells (adMSC) on plasma-treated PEEK. There is another method, which called as corona treatment, which is a glow discharge very similar to plasma treatment. Except for laboratory conditions, it usually operates in the air at atmospheric pressure [16]. Another study focuses on PEEK tuned by argon plasma treatment to enhance its wettability and cytocompatibility. Changes in surface properties of the plasma-treated surface studied about the adhesion, proliferation, and metabolic activity of mouse fibroblasts (L929) and human osteoblast (U-2 OS) in vitro. The plasma treatment led to substantial changes in the surface chemistry, polarity (wettability) of PEEK samples. Furthermore, polymer surface morphology and roughness were significantly altered [42].

UV-light.

Another technique to increase oxygen content and decrease contact angle which means enhancing adhesive bonding of PEEK is a UV treatment, which accompanied by employing light bulbs emitting light at wavelengths between 172nm and 308nm [62].

Accelerated Neutral Atom Beam (ANAB) Surface Treatment.

Accelerated Neutral Atom Beam (ANAB) technology is a low-energy, accelerated particle beam that useful as a method for nanoscale surface treatment. This technique is created by the acceleration of unbonded neutral argon (Ar) gas atoms with very low energies under vacuum, modifying the material surface to create a shallow depth of 2-3 nm [63]. This method is used for the modification of the surface and changes the surface topography, structure, and energy, especially in medical implants like PEEK. Several studies showed this technique enhanced the bioactivity of the PEEK, making some nanoscale texture on the PEEK surface, which causes better properties than untreated PEEK like increased wettability and improved human osteoblast cell adhesion and

proliferation [64, 65]. There is schematic image in **Figure 1** which shows different methods to enhance bioactivity of the PEEK.

Laser technique and treatment.

Laser technology is popular in many areas like communication, military, industry, medical, and some other fields, which the most popular one presented in Table 1. The laser method is used a lot in medical fields like surgery, dermatology, and cancer therapy, dental and, biomaterial surface modification [32, 66]. Enhancement of PEEK surface bioactivity with the laser technique has been investigated in recent decades. This method has some advantages, like low cost, high resolution, high-operating speed, and the fact that lasers do not change the bulk properties of implant and just treat a certain surface, which makes it an interesting method among other methods in polymer surface modification [30]. Considerable numbers of researches have been conducted regarding laser method for polymer modification and investigated the effect of the different laser device and laser parameters on the surface properties and cell adhesion, which is caused by the change of wettability and functional group of the surface [27, 67, 68].

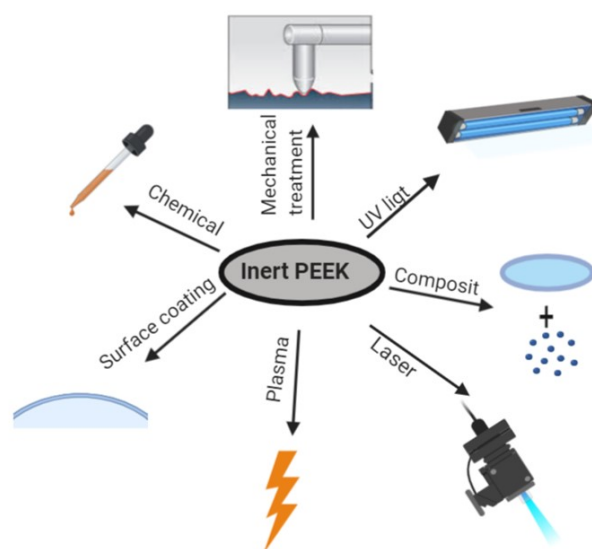


Figure 1. Scheme of current methods to improve the bioactivity of PEEK

Laser Process Fundamentals and its effect on surface properties.

Laser technique is one of the simplest techniques to modify both surface topography and chemistry. In this method, a laser beam is emitted directly on the surface of the material and optical energy provided by the laser is absorbed by a material surface, then three kinds of the process may take place, which is named 1. Thermal processes: In this case, increasing temperature of the material, by the emission of the laser beam on the surface, led to melting or vaporization. This induces the modification in the surface roughness. 2. Photochemical processes: in this process, the high-emitted energy from the laser is able to break the chemical bond molecules of the treated surface and cause chemical modification of surfaces. Because of the high photon energy, ultraviolet (UV) lasers are the most common ones in this case and 3. Photophysical processes: here both thermal and photochemical processes take place and can influence the surface roughness and chemistry simultaneously [69]. Which all of these three processes presented in schematic image. below (Figure 2).

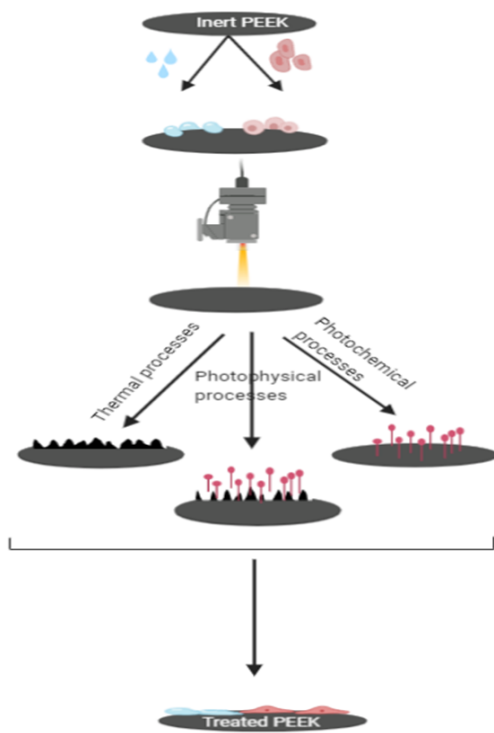


Figure 2. Scheme of laser technique and the way it works to improve the surface bioactivity of PEEK.

On the other hand, various studies have shown that surface properties like charge, chemistry, roughness, and wettability are determining factors on cell adhesion and cell behavior. Thus, surface properties can affect cell behavior and biomaterial success in the body. Therefore, a considerable amount of researches has done to control surface physiochemical properties. Among all of this research and modification, laser technology is so attractive due to the properties, mentioned before [67, 70-74].

Laser categories and basics.

There are variable operation parameters in laser such as pulse duration/length, wavelength, and power, which have a relationship with the surface modification that scientists are interested in them. A laser technique usually uses for surface

topography modification and to create some micro and nanostructure but sometimes can be used to alter the chemistry of the surface. All of these can have an effect on the surface properties like roughness and wettability, which are critical factors for cell adhesion [67, 75].

Typically, each laser system has three main components: 1. an active medium, 2. a pump source, and 3. a mirror system. Which active medium placed in the center of the laser cavity and determine the out beam and the wavelength of the laser, the pump is necessary to start the population inversion inside the active medium, and two mirrors are for producing several reflections in short distance to increase the number of the photons [69].

There are several categories for the laser device. The most popular one based on the active medium, divide into four main groups 1. Gas, 2. Solid, 3. Liquid, and 4. Semiconductor laser. The most popular one in each group is listed in Table 2. The gas and solid-state laser are popular ones for biomaterial surface modification, which are described here. In addition, there is another category based on one operation regime, which divided into two main groups 1. Continuous -wave (CW) laser and 2. Pulsed laser. There is some difference between these groups, but the fundamental difference is the length or duration of the laser emission. The pulse laser allows the user to have control over the beam duration and intensity, but the continuous laser is emitted one beam but pulse laser emitted in pulses and does not need to operate in the steady-state regime. Continuous-wave (cw) operation continuously pumped and continuously emits light and operates in a steady state regime. A helium–neon laser with a wavelength of 1153 nm was the first continuous-wave laser.

In comparison, pulsed lasers can make much higher peak power than CW lasers [24, 76, 77]. There is a new range of gain media in pulsed lasers, which called excimer lasers. These are based on the unstable molecular species, called exciplexes and they can lase in the far UV. The popular excimer lasers are XeCl, and KrF, which are used in many surface modifications [26, 33, 78].

Table 1. Some popular laser with different gain media [69].

| Laser type | Active medium | Wavelength range(nm) |
|-----------------------|---------------|---------------------------------|
| Solid- state | Nd:YAG | 355- 532-1064 nm |
| Solid- state | Ti: Sapphire | 700-1000 |
| Solid- state | Ruby | 628 |
| Solid -state | Nd:YVO4 | 1064 nm, 532 nm, 355 nm, |
| Solid- state | Yb:YAG | 1030 nm, 515 nm, 343 nm, 257 nm |
| Gas | HeNe | 633 |
| Gas(Excimer) | XeF | 351 |
| Gas(Excimer) | KrF | 248 |
| Gas(Excimer) | KrCl | 222 |
| Gas(Excimer) | ArF | 193 |
| Gas-Ion | Argon | 488 |
| Gas-Ion | Krypton | 531 |
| Metal Vapor | Cu | 511-578 |
| Semi-conductor | InGaAs | 980 |
| Semi-conductor | InGaAlP | 635-660 |

Solid-state laser.

A solid-state laser is a kind of laser that uses solid as a laser medium or host medium. Glass or crystalline materials are used as the laser medium, and there are some materials, used as a

doping substance inside the host medium. The first solid-state laser was a ruby laser. In this kind of laser, light sources such as flash tubes, flash lamps, arc lamps, or laser diodes are used as a pumping source. The popular host materials, used for laser

medium are, Ytterbium-doped glass, Neodymium-doped glass (Nd:glass), Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG), sapphire (Al_2O_3) Neodymium-doped [79]. Nd:YAG is the most popular one, which already used in many studies, especially polymer surface modification. The result confirmed that Nd:YAG laser enhanced the wettability and surface bioactivity after treatment like polypropylene[34], poly ethylene [80] and in some case, it showed that along with improving the wettability after treatment of polycarbonate the surface cell adhesion and proliferation improved, which were some promising result for the surface bioactivation [81]. All of these results and others have shown that Nd:YAG laser has potential as a precise, clean and simple surface modification technique for an extensive range of materials including polymers like PEEK [34]. In one study PEEK was exposed to a nanosecond pulsed Q-switched Nd:YAG laser radiation ($\lambda = 1,064 \text{ nm}$) and the result showed after the laser treatment the surface energy was increased (from 44.9 to 78.5 mJ/m^2), and also enhanced the wettability. Also, chemical analysis showed an increase in hydroxyl and carboxylic groups, along with a decrease in the original carbonyl groups which formation of these functional polar groups enhanced the surface wettability [82]. Riveiro et al. investigated the role of pulsed Nd: YVO4 laser irradiation wavelength on the PEEK surface modification under three laser wavelengths (1064, 532, and 355 nm) to determine the most suitable process to increase the roughness and wettability of the surface. PEEK surface changes were very different as a function of the laser radiation. The PEEK surface burned at 1064 nm, while the 532 nm laser radiation ablated the surface and created some grooves with a mean width of 100 μm . The 355 nm laser radiation just melted the surface slightly that was insignificant, but this laser radiation induced the formation of some polar groups like carboxyl and peroxide on the surface, which enhanced the surface wettability. The result showed that ultraviolet (355 nm) is the most suitable one to improve surface wettability of PEEK [32]. In another case, Ti: Sapphire laser at 800 nm has been used for PEEK treatment in vivo animal test and the influence of the roughness on the biological activity and osteogenic efficiency investigated. The treated PEEK implant inserted on rabbits and demonstrated a superior bonding strength of the bone/implant interface [83].

Gas laser.

A gas laser is a laser that mixture of gases used as a laser medium which is packed up in a glass tube in which an electric current is discharged through gas inside the laser medium to produce laser light. Some commonly used gas laser is, Helium (He) – Neon (Ne) lasers, argon ion lasers, carbon dioxide lasers (CO_2 lasers), carbon monoxide lasers (CO lasers), excimer lasers, nitrogen lasers, hydrogen lasers, etc. [84]. The type of gas used as a laser medium can determine the laser's wavelength or efficiency. In one study, XeCl excimer laser (308nm) [33] were used for the treatment of the PEEK in lap-shear experiments. The energy density applied was above the ablation threshold, which led to chemical modification of the surface through surface roughening or ablation. The result showed lap shear strength increased from approximately 3MPa to 18MPa. In another case, CO_2 laser has been used to modify the PEEK surface, and the result showed that the surface crystallinity was decreased with an increment of the

laser intensity and also the surface roughness increased, but the surface chemistry stated intact [85].

Laurens et al. using ArF excimer lasers ($\lambda = 193 \text{ nm}$ with pulse duration = 20 ns) modified PEEK surfaces below the ablation threshold. The chemical modification was different and depended on the gas used in the process. Under neutral conditions, carbonyl groups of PEEK structure were broken, but in the air atmosphere and the presence of environmental oxygen, increased the carboxylic functions. Finally, the polar functional groups increased at PEEK surface, which led to adhesion, increased after laser treatment [33].

Michaljaníková et al. also observed similar results. In this case, the PEEK surface was treated with KrF Excimer laser UV radiation ($\lambda = 248 \text{ nm}$ and the wettability was increased which was because of the increase in roughness, and formation of the oxygen polar groups formed on the PEEK treated surface [86]. Zheng et al. investigated the enhancement of biocompatibility of PEEK surface after CO_2 laser ($\lambda = 10,600 \text{ nm}$) and plasma treatments. Chemical analysis confirmed the formation of the polar groups like carboxylic groups on the surface and in vitro biocompatibility test showed that MC3T3-E1 pre-osteoblast cell adhesion and proliferation were increased after laser treatment [87]. Another group implanted the laser-treated PEEK cage for fusion in the sheep model, and they observed the good fusion and higher deposition of the mineralized matrix after six months of implantation [88]. Bremus-Koebberling et al. using a frequency-tripled solid-state laser (JDSU, Milpitas, CA) of 355 nm wavelength and 38 ns pulse duration, produced nano-grooves by laser interference patterning ($\lambda = 355 \text{ nm}$, pulse duration = 38 ns) and evaluated the effect of this pattern on the cell alignment. The result has demonstrated the width of the nano-grooves, and the groove depth influences the cell (B35 neuronal) alignment, which confirmed the cellular response is depend on surface nano-topography [89]. In this study, pulsed excimer laser (at 193 nm) was used to enhance the adhesive bonding properties of PEEK. Results showed that several types of treatment occurred. First, the surface treatment induces a cleaning of the initial surface, surface amorphization and modifies the chemical composition of the material and finally the enhancement obtained for laser fluency lower than the ablation threshold [90]. In another study, excimer laser was used at 193 and 248 nm. As mentioned before modification by an excimer laser at 193 nm make some polar groups on the surface which increases the adhesive properties of the PEEK, but another side the higher concentration of these functional groups may also have a negative effect on the mechanical properties of the modified surface of the PEEK. Also, here it was shown that laser treatment at 248 nm did not make significant improvement in adhesion properties of the PEEK surface and that may be the result of the thermal degradation of the surface at 248 nm wavelength. The result showed there is a relation between laser wavelength and surface modification at 193nm dependent on the laser wavelength. At 193 nm, oxidation under photon irradiation made the formation of polar groups like carboxyls and hydroxyls thus increased the surface hydrophilicity but at 248 nm, surface decarbonylation led to limit the formation of polar groups, so no significant change was observed [33].

Table 2. Laser application [18, 91-93].

| Medicine | Communications | Science and technology | Military | Industries |
|---|--|---|--|---|
| Bloodless surgery Remove kidney stones Treatment of liver and lung diseases Remove tumors Cancer diagnosis and therapy Eye lens curvature corrections Fiber-optic endoscope to detect ulcers in the intestines To study the internal structure of microorganisms and cells To create plasma Dentistry and implant Cosmetic treatments such as acne treatment, cellulite and hair removal | Optical fiber communications Underwater communication networks Space communication, radars and satellite | Study the Brownian motion of particles Count the number of atoms in a substance Retrieve stored information from a Compact Disc in computer Store large amount of information or data in CD-ROM Measure the pollutant gases and other contaminants of the atmosphere Produce three-dimensional pictures in space without the use of lens Detect earthquakes and underwater nuclear blasts | Determine the distance to an object by Laser range finders Measuring very small angle of rotation of the moving objects by ring laser gyroscope Secretive illuminators for reconnaissance during night with high precision To dispose the energy of a warhead by damaging the missile | To cut glass and quartz In electronic industries For heat treatment in the automotive industry Collect information from bar code printed on the product In the semiconductor industries for photolithography Drill aerosol nozzles |

4. CONCLUSION

PEEK has promising advantages, because of the appropriate properties, in biomedical application like bone and dental implant but the weakness of this polymer is bio-inertness. Therefore, in recent decades, PEEK surface modification has been a very crucial issue for utilization of the PEEK polymer in medical applications and among several existing modification methods, laser technique is becoming promising methods because of its appropriate properties. There is a different laser system with different parameters, which can be controlled to create a variety of surface modifications. Laser device can change surface topography and (sometimes depend on laser wavelength) chemistry which led to alter surface wettability and surface adhesion. Different laser devices based on the gain medium, pulse duration, and wavelength are studied in many types of researches,

and it has shown that laser parameters can affect surface properties in different ways. In all of these researches, it was not exactly shown which one is the best and has the most effect on cell adhesion. All studies show that laser treatment enhances the surface properties like roughness and wettability and all surface treatments improve adhesive bonding of PEEK and also it has proved that laser parameters have an important role in surface modification and changing these parameters can change the surface properties. Hence, recognizing the different laser system and their parameters and the ability to control these parameters is essential to achieve the most appropriate surface treatment of the PEEK to gain the most bioactive PEEK surface for biomedical application.

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