How to Cite:
Jani, G. H., Fatalla, A. A., & Mahdi, A. K. (2022). Evaluation of implant bonding strength for PEKK with strontium hydroxyapatite as composite and coating implant material. *International Journal of Health Sciences*, *6*(S5), 9532–9544. https://doi.org/10.53730/ijhs.v6nS5.11670

Evaluation of implant bonding strength for PEKK with strontium hydroxyapatite as composite and coating implant material

Ghasak H. Jani
Assistant Professor, Department of Prosthodontics, College of Dentistry, University of Baghdad.
Corresponding author email: dr.ghasak@codental.uobaghdad.edu.iq

Abdalbseet A Fatalla
Professor, Department of Prosthodontics, College of Dentistry University of Baghdad.

Mahdi. A.K
Assistant Professor, Department of Surgery and Obstetric, College of Veterinary Medicine, University of Baghdad.

***Abstract*---**To date, there has been a lot of interest in the development of medical/dental implant materials. Many studies have been conducted in recent years on the development of composites, particularly those based on calcium phosphate bio-ceramic, because their structure is comparable to that of human bone. The aim of the study was to evaluate the bond strength between the bone and pekk implant with strontium hydroxyapatite after different periods of implantation (2, 6) weeks in rabbit tibia by push out test.60 polymer implants, 3.0 mm in diameter and 8mm in length (20 control pure PEKK, 20 composite SR HA /PEKK implant and 20 implant coating with strontium hydroxyapatite by RF magnetron sputtering. The assess surface topography was done by using Scanning electron microscope. The screws were implanted in twenty healthy adult new zeeland rabbits each tibia received three, one coated with sr ha, one composite SR HA / PEKK and third pure PEKK. Push out test was done to determine the peak force necessary to remove the implant from tibia bone after different periods (2 and 6 weeks) of implantation. Bonding value for PEKK coated with Sr-HA) was statistically significantly higher than composite and pure pekk after 2weeks and composite SR HA /PEKK-significant higher after 6 weeks. There was significant increase in bonding force value with time. The study shows that the PEKK with added SR HA as composite or coating achieved better osseointegration than pure PEKK in vivo.

International Journal of Health Sciences ISSN 2550-6978 E-ISSN 2550-696X © 2022.
Manuscript submitted: 9 April 2022, Manuscript revised: 18 June 2022, Accepted for publication: 27 July 2022

***Keywords*---**pushout Test, Composite, coating, Strontium hydroxyaptite.

1. Introduction

The development of medical/dental implant materials is intensely interested to date. During the recent years, many studies were carried on about the development of composite, especially based on the calcium phosphate bio-ceramic because their structure is similar to the human bone. [1] Today, the biopolymers have been focused and used as an alternative to metal implant materials in medical treatments. Polyetheretherketone (PAEK) family are one of the interested biopolymers implant materials. It is a high performance semi-crystalline thermoplastic polymer that was first developed as a polymeric biomaterial for joint prostheses or plates for fracture fixation in the field of orthopedics and traumatology. [2]. PEKK (PolyetherKetoneKetone) a high performance thermoplastic material based on a highly stable backbone of PolyetherKetoneKetone (PEKK). Its semi-crystalline structure offers an outstanding combination of mechanical and thermal strength together with chemical and fire resistance. [3] Beside of the good biocompatibility, excellent chemical resistance and good mechanical properties, it also has a closer Young's elastic modulus to the human cortical bones. [4]

Modifying to improve its bioactivity can reduce the rate of implantation failure caused by poor osseointegration and avoid secondary surgeries, reducing the economic burden of the patients. Currently, two strategies are available for improving the bioactivity of polymer including composite preparation (incorporating bioactive materials into polymer) and surface treatment/coating with physical/chemical methods [5] Among these strategies, impregnating bioactive materials into polymer has become an attractive approach for improving the bioactivity while maintaining its mechanical properties. [6] Ceramics with bone-bonding ability are defined as bioactive ceramics, such as hydroxyapatite (HA), calcium silicate (CS), bioglasses, etc. Synthetic HA material is biocompatible and bioactive and is clinically used as an important bone substitute.[7]

In recent decades, composite materials have increased their popularity in many sectors because of their versatile uses, ease of preparation, availability of raw materials, eco-friendliness, improved mechanical for desired products, low density, and low cost. Most composite materials are composed of a polymeric matrix. The processes of bone resorption and formation are tightly governed by a variety of systemic and local regulatory agents. In addition, minerals and trace elements affect bone formation and resorption through direct or indirect effects on bone cells or bone mineral. Hydroxyapatite (HA) is a biocompatible and osteoconductive material which exhibits high affinity for host bone tissues through mineral surface reactions. [8] Some trace elements closely chemically related to calcium, such as strontium (Sr), have pharmacological effects on bone when present at levels higher than those required for normal cell physiology. Strontium (Sr) promotes osteoblast proliferation and inhibits osteoclast proliferation and positively affects bone regeneration. [9].

This study concentrated on the studying the bond strength between the bone and implant as effect of bioactivity of newly manufactured PEKK /nano HA-strontium after different periods of implantation (2, 6) weeks in rabbit tibia. No study was done that manufactured PEKK /nano HA-strontium composite as implant materials by compression mold technique, also no study was done that used PEKK implant material coated with nano HA/strontium as implant materials

2. Experimental Work

Preparation of Sr-HA/PEKK composite specimens

Sr-HA/PEKK composites with 30% Sr-HA filler reinforcement was developed. Methods of powder mixing and compression molding use. [10]. To generate a uniform suspension, appropriate volumes of Sr-HA powder and PEKK powder are codispersed in a suitable solvent. The solvent is then removed by drying the powder combination in an oven, and the powder mixture is then deposited in appropriate molds to create the desired shape. At 35MPa pressure, the powder combination and the molds are warmed to a temperature of around 150°C. The temperature is then raised to 350–400°C while the pressure is maintained at 15 MPa. The polymer melts when PEKK reaches its melting point, but the bioactive filler particles remain solid. After maintaining the temperature for 10 minutes, the composite implants are air-cooled to 150°C to reduce thermal strains and cracking. The resulting material is a mixture of solid PEEK matrix and nanofillers scattered inside it after cooling . [11]

The composite sheet was removed once the die was opened. The sheets were 20cm * 20cm* 3mm in size, and the samples were in sheet form. Polymer sheets were then cut and machined to the appropriate test specifications using a computerized cutting machine CNC. [12]

Preparation of PEKK coating with Sr-HA specimens

Preparation of target

In order to perform the RF plasma sputtering of SR HA powder, a circular target of 50mm in diameter and 3 mm in thickness was prepared .The target was made by mixing (30 g) of SR HA powder, then loaded and pressed in cylindrical stainless steel mold with dimension of 50 mm in diameter and 3mm in height, the pressing was done under 8 tons pressure for 2 min. using electrical press, to obtain uniform target and to avoid target fracture . The samples were allowed to dry gradually at room temperature for 24 hours to avoid cracks.[13]

RF magnetron sputtering

Radio frequency magnetron sputtering was performed in the system chamber which was made from stainless steel. The target was attached to the anode (positive charge) of system and the substrates were attached to cathode (negative charge) rotating disc.

The PEKK substrates and SR HA target were introduced inside the sputtering chamber then the chamber window was closed tightly. The distance between substrates and target was fixed to 10 cm. The break-in prior to deposition from the HA target was conducted at a ramp rate of 5 watts (W) per minute up to the operating power of 150 W, whereby the source shutters were kept closed. The base pressure was below 5×10^{-2} Pa, with an argon gas flow rate of between 15 and 20 Sccm, and a throw distance of 100 mm. During sputter deposition, the chamber pressure was maintained at 3×10^{-2} Pa. The substrates were heated gradually to reach balance temperature of 80° C. The deposition was done at 2 rpm in order to increase the uniformity of distribution.[14]

In present work, SEM was used to reveal the microstructure of neat PEKK, nanocomposites samples and coating samples. It was used to diagnose the phases and nanoparticles distribution of samples. Also, SEM was mainly used to characterize the morphology of the prepared samples. Morphology of surface of neat PEKK, nanocomposites and coating samples was studied using scanning electron microscope, its specification is Hitachi S4700 EDAX ApolloX Genesis software.[15, 16] [17]

Ten healthy adult New Zeeland rabbits weighing 2 -2.5 kg were used. Antibiotic cover with oxytetracycline intramuscular injection was given to exclude any infection. Rabbit were left for two weeks in the same environment before surgical operation. The surgical equipments were sterilized. Sterile gloves, gowns and surgical masks were used. The rabbits were anesthetized by (intramuscular injection of ketamine hydrochloride (1ml/kg Body weight) and xylocaine 2% (1ml/kg B.W).

Both legs were shaved and cleaned with chlorhexidine alcohol. The rabbit was placed in a sterile surgical table. Longitudinal incision was made along the medial aspect of the rabbit right tibia. The periosteum was reflected dorsally to the physis. A hole was made, approximately 3 mm from the proximal physis with straight hand piece (strong 90,Korea) with a round guide drill of 2.0mm in diameter. The screw was inserted and the same procedure was repeated to the other leg, where another screw was inserted.

Suturing of muscles was done with absorbable catgut suture followed by skin suturing with silk suture The operation site was sprayed with local antibiotic (oxytetracycline spray),then long acting systemic antibiotic (oxytetracycline 0.5ml/kg B.W.) . Postoperative care was performed by giving oxytetracycline antibiotic (local and systemic) for 3 days after surgery. After the end of implantation period, the rabbits were anesthesized and incision was made to expose the implant to measure bonding strength by push out.

3. Results

Scanning electron microscope

Scanning electron microscope allows for direct observation of the morphological and structural features of samples. So, in order to see the morphology of the nanoparticles used in this work, the SEM images were taken at a nanometer and micrometer scale. The SEM images are shown in three different magnifications (500 nm , 1 µm , 200 µm).

Figure (1) shows the scanning microscopy image of pure PEKK was characterized by homogenous and smooth surfaces and some voids or defects were seen. at nanometer magnifications were seen distribution of the particles is such that they are loosely packed.

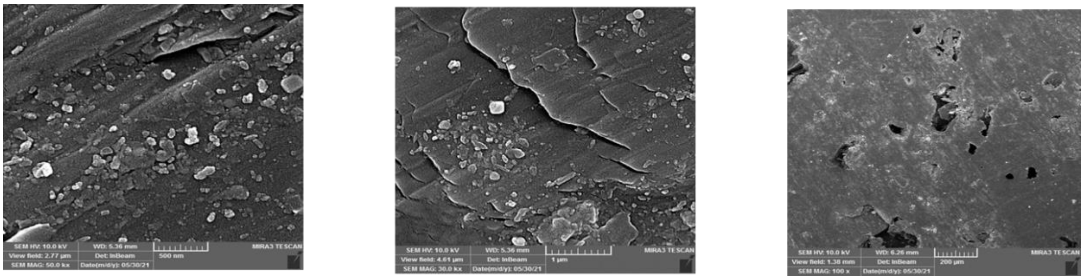

Figure (1) shows the scanning microscopy image of pure PEKK

Figures (2) manifests the representative surface morphology of PEKK composite group with 30% of HA SR nanoparticle content in composites, this SEM photos exhibited a homogenous morphology with dispersion nanoparticle and voids is less than control pure PEKK. Also, at nanometer magnifications it can be observed that different sizes of spherical shaped of nanoparticle material were dispersed randomly in PEEK matrix The SEM photos show very few of micro-cavities structure, this indicates a fairly interaction between the components.

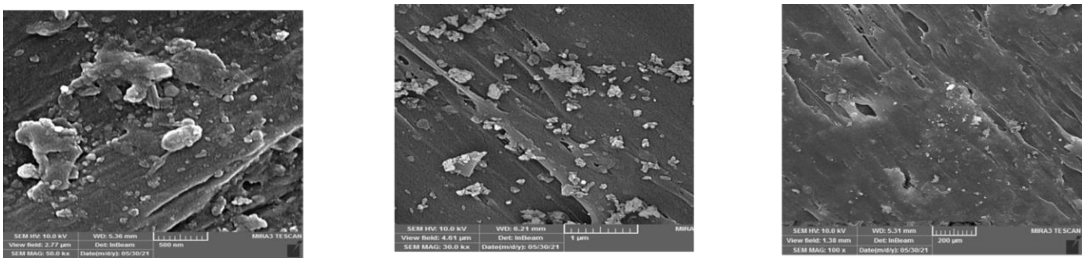

Figure (2) shows the scanning microscopy image of PEKK composite with 30% of HA SR

Figures (3) manifests the representative surface morphology of PEKK coating group, Some distinct cracks were seen in the coating So, in order to see the morphology and the particle size of the nanoparticles used in this work, the SEM images were taken at a nanometer scale, shows the scanning microscopy image of hydroxyapatite nano-particles. It can be clearly seen that nanoparticles form some agglomerates (white spots).

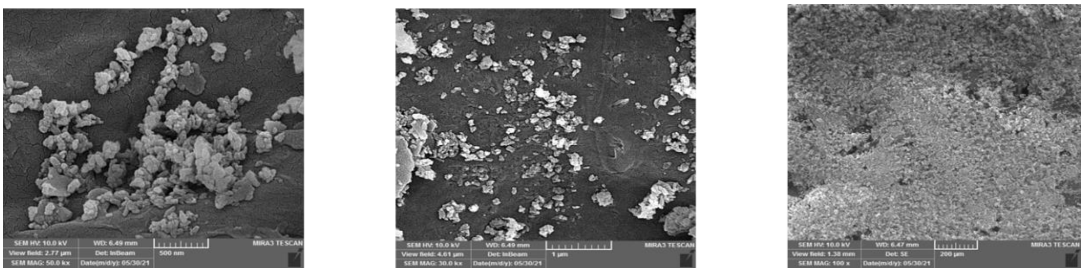

Figure (3) shows the scanning microscopy image of PEKK coating with 30% of HA SR

Clinical observations

All rabbits tolerated the implantation well after surgery and eating, moved normally within one week. At sacrifice day, no sign of negative clinical observations was noted around the implant sites in any of the animals with positive tissue reaction. All implants were found stable in the bone and they could not be moved with manual force, no peri-implant defects were detected at the coronal aspect of any implant specimens after 2 and 6 weeks of healing periods.

Push out test

The push out forces mean values for different groups of pure polyetherketoneketone (PEKK), strontium hydroxyapatite /polyetherketoneketone Sr-HA /(PEKK) composite and strontium hydroxyapatite coating PEKK implant after 2 & 6 weeks of implantation were summarized by box plot in figure 4. In the results of present study the push out force at time of 2 weeks after implantation showed that the (Sr-HA coating PEKK) implants had the highest mean value, followed by (Sr-HA /PEKK composite) implants, while the pure (PEKK) implants had the lowest mean value. At the time of 6 weeks after implantation the results showed that the (Sr-HA /PEKK composite) implants had the highest mean value also, followed by the (Sr-HA coating PEKK) implants, while the pure (PEKK) implants had the lowest mean value.

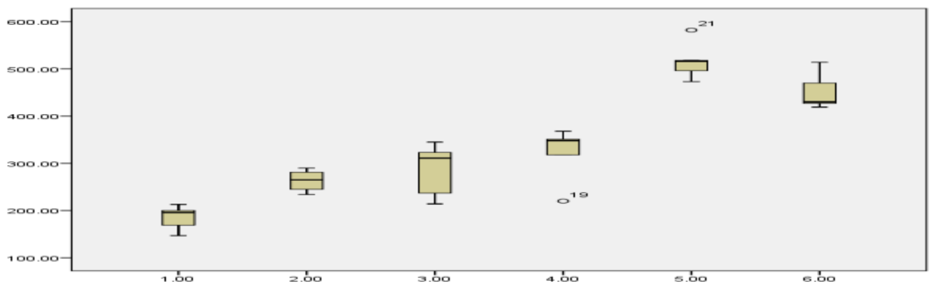

Figure (4) Box plot for push out force (N) values of all test groups

At 2 weeks time interval, the push out force values that's needed to push the (Sr-HA coating PEKK) implants which represent (286 N) the highest mean value in this period, followed by (Sr-HA /PEKK composite) implants with mean value (263 N), and the lowest mean value of force needed to push (pure PEKK) implants was (185 N).

The quality of means between groups of implants tested after 2 weeks were analyzed by ANOVA test. This test demonstrates a statistically highly significant difference at P< 0,000 as in table 1

Table (1): descriptive analysis of Push out Force(N) for all tested groups after 2 and 6 weeks interval and ANOVA test

Groups	Descriptive statistics					Comparison	
	Mean	S.D.	S.E.	Min.	Max.	F-test	p-value
Control 2 weeks	185.0000	26.59887	11.89538	147.00	213.00	9.283	.004
Composite 2 weeks	263.0000	23.56905	10.54040	234.00	290.00		
Coated 2 weeks	286.0000	57.14018	25.55386	214.00	345.00		
Control 6 weeks	321.0000	59.26213	26.50283	220.00	368.00	22.134	.000
Composite 6 weeks	517.0000	40.63250	18.17141	473.00	582.00		
Coated 6 weeks	452.0000	39.89361	17.84096	419.00	514.00		

Multiple Comparisons among the implant's groups were done by using the Post hoc/Bonferroni test, this test showed a statistically highly significant difference between (Sr-HA /PEKK composite) group and other two groups, and showed a statistically significant difference between (Sr-HA coating PEKK) group and (pure PEKK) group as shown in Table (2).

Table (2) Post hoc/Bonferroni test among different tested implant groups after 2 and 6 weeks

Groups		Mean Difference	Std. Error	Sig.
Control 2 weeks	Composite 2 weeks	78.00000-*	24.57099	.024
	Coated 2 weeks	101.00000-*	24.57099	.004
Composite 2 weeks	Coated 2 weeks	23.00000	24.57099	1.000
Control 6 weeks	Composite 6 weeks	78.00000-*	24.57099	.024
	Coated 6 weeks	101.00000-*	24.57099	.004
Composite 6 weeks	Coated 6 weeks	23.00000	24.57099	1.000

* The mean difference is significant at the 0.05 level.

At 6 weeks' time interval, the push out force values that was needed to push the (Sr-HA /PEKK composite) implants was the highest mean value (517 N), followed by the (Sr-HA coating PEKK) implants with mean value (452 N), and the lowest mean value of force needed for pushing the (pure PEKK) implants was (321 N). The quality of means between groups of implants tested after 6 weeks were analyzed by ANOVA test. This test demonstrates a statistically highly significant difference at P< 0,000 as in table (1).Multiple Comparisons among the implant's groups were done by using the Post hoc/Bonferroni test, this test showed a statistically highly significant difference between (pure PEKK) group and other two groups(Sr-HA coating PEKK), (Sr-HA /PEKK composite) and showed a statistically non-significant difference between (Sr-HA coating PEKK) group and (Sr-HA /PEKK composite) group as shown in Table 2 The quality of means between all groups of implant tested after 2 and 6weeks were analyzed by ANOVA test, as in table (3).

Table (3) ANOVA test for all implant groups of two intervals

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	385306.667	5	77061.333	40.981	.000

Multiple Comparisons among different tested groups of implants after 2 and 6 weeks intervals, done by using the Post hoc/Bonferroni test, this test mentioned that, there was a statistically highly significant difference between (pure PEKK) groups at 2 and all groups at 6 weeks' time intervals for implantation , as shown in table (4), meanwhile comparison among groups of (Sr-HA coating PEKK)and (Sr-HA /PEKK composite) after two period of implantation 2 and 6 weeks, as shown in Table (4).

Table (4) Post hoc/Bonferroni test among different tested implant groups at 2 and 6 weeks intervals

2weeks / 6 weeks	Control		Composite		coating	
	Mean Difference	Sig.	Mean Difference	Sig.	Mean Difference	Sig.
control	136.00000*	.001	58.00000	.675	35.00000	1.000
Composite	332.00000*	.000	254.00000*	.000	231.00000*	.000
Coated	267.00000*	.000	189.00000*	.000	166.00000*	.000

*. The mean difference is significant at the 0.05 level

4. Discussion

Scanning electron microscope

The qualities of polymer nanocomposites are largely determined by their shape and structure. Several factors influence the morphology of nanocomposite materials, including particle nature, particle shape, particle size, particle dispersion, component ratios, and processing conditions. the morphology of the polymer nanocomposite was investigated with high-resolution SEM operated at an acceleration voltage of 20 kV.

Figure shows SEM images of nanocomposites group with 30% nanoparticle content ratios. For nanocomposites, scanning electron microscopy (SEM) proved it. Increased the weight fraction content of the PEKK matrix material, which had a significant impact on the mechanical properties of the produced polymer composite, particularly in the 30% SR HA/ PEKK group.[18]

When SR HA nanoparticles are added to polymer nanocomposite, the morphology of the polymer nanocomposite changes when compared to the morphology of pure or plain polymer. Due to fine and homogeneous dispersion of SR HA in PEKK Nano-composite, which is expected due to proficient and good processing conditions during the sample preparation, domains were larger when 30% SR HA was added. This good dispersion of SR HA has improved mechanical properties and also effected on other properties.[19]

When the weight fraction of SR HA in the polymer composite is increased, agglomeration of the filler occurs, because of their high specific surface area, have strong an inclination toward gathering and form pack or micron-sized clusters resulting in an un uniform distribution of the nanonfiller. Nanoparticles tend to form hard agglomerates; hard agglomerates are accumulations of isolated particles connected to each other by attractive physical interactions. It's possible that the agglomeration of soft nanoparticles, can inhibit crack initiation and propagation.[20, 21]

Push out test

The push out test is a popular mechanical test used in vivo studies to assess the strength of the connection between the bone and implant surface, and the findings disclose the shear bond between the two. It is also a good test for cylindrical implant specimens.

Push out test values for Two weeks' time period

In this study, the bone implant bond strength of (Sr-HA / PEKK composite) and (Sr-HA coating PEKK) implant specimens were evaluated and compared with pure PEKK implant specimens. The force that needed to push the implant specimens out was measured after 2 weeks of implantation in the rabbit tibia. Statistical calculation showed a higher push out force values that was needed to push the (Sr-HA coating PEKK) implant out than the (Sr-HA / PEKK composite) and pure PEKK respectively after 2 weeks implantation.

The increase in the roughness of the coated specimens could explain the results. This discovery is in agreement with[22], who discovered in 2008 that the bond strength of implants after osseointegration is proportional to surface energy and surface roughness. The bonding strength increased as the surface roughness increased.

Alteration in chemical composition by (Sr-HA / PEKK composite) to improve surface roughness , showed more roughness and irregularities at the surface than pure PEKK this result was agree with[23](Doornewaard *et al.*, 2019), in spite of different in material and method.

Another reason for the improved osteointegration could be development of hydrophilicity of the surface of the (Sr-HA / PEKK composite) and (Sr-HA coating PEKK). The encouraging effect of filler on PEEK is attributed to improving wettability (reducing contact angle), forming micro irregularities on the surface (rough surface), directed to increase bond strength, with no adverse effect on cell viability, increasing cell growth and proliferation, all of which are granted and agreed upon by [24-26].

One more potential reason is the presence of calcium and strontium (which has similar structure to calcium) within the composite and coating material, this in coincide with [27] who concluded that the osseointegration is quicker, after superficial Ca++ions treatment, they stated that Ca++ions assumed and increases the biocompatibility with the host.

Because sr's high activity is linked to its high solubility (53.8 g/100 mL), sr+2 is released and diffused to reach the osteoblast, where it stimulates osteoblastic cell proliferation and differentiation while inhibiting osteoclast activity and differentiation, resulting in increased matrix deposition and, ultimately, new bone formation. this agreed with [28] who found increased proliferation of osteoblast in cell culture .

Two processes are used to integrate Sr+2 into bone: First, a quick uptake mechanism based on osteoblast activity, in which Sr+2 is absorbed via ion exchange processes with Ca2+, or by binding to osteoid proteins, or both. This mechanism eventually reaches a point of saturation. The incorporation of Sr2+ ions into the crystal lattice of the bone mineral through the a second, slower mechanism. This suggests that the mechanisms of action are a fast uptake into new bone and a longer-term exchange process in older bone. [29].

When hydroxyapatite partially dissolves, the surrounding fluids become rich in calcium and phosphate ions, which appears to induce the precipitation of "bone-like" apatite on the implant surface. This "bone-like" apatite can then trigger cellular differentiation and subsequent bone formation (apatite plus osteoblast cells), which could explain why HA-coated implants have a high rate of osseointegration. [30]**.**

Push out test values for six weeks' time period

The results showed that all groups have more bonding values than Pure PEKK implants after six weeks interval. This increase could be attributed to the amount of new bone that was transformed to mature bone at 6 weeks, as well as the higher amount of new bone formed with the constant influence of local contexts such as increased wettability, increased roughness, and the elevated degree of new bone formation, which could reflect the greater bond strength at the implant-bone interface than the untreated PEKK implant. as suggested by [31].

After 6 weeks which may be due to the strontium is dose dependent so with time more strontium released from coating layer, so Sr effect was reduced and the result is more depended on HA action, while composite continue to release sr and high activation of Sr to osteoblast than HA ,so the force that needed to push the implant specimens out was higher to(Sr-HA / PEKK composite) than the(Sr-HA coating PEKK) after 2 weeks implantation in the rabbit tibia.

Effect of time on bone implant interface bond strength

The result of this study mentioned that the force value needed for push out increase as time progress because of bone remodeling and rapid bone formation around the implant, this mean progress in mechanical capacity and osteointegration with time, these results accepted with results of [32], in spite of material and treatment usage in our study differed than the mentioned study.

Also this agreed with the study of [33] that been proposed that this improvement was due to an increase in bone-implant contact over time as a result of ongoing bone development and remodeling surrounding the implant throughout the healing process, which improved the mechanical capacity significantly, and agreed with the study of [34] that found increase in the torsional strength began after 4 weeks of unloaded healing and there was a significant increase with time throughout the initial 6 weeks.

Additional explanation for the improvement in bonding force by[35] may be related to the maturation of bone from woven to mature lamellar bone; between intervals of time of healing (2 and 6 weeks), these results were provided in the study of [36].

4. Conclusion

Strontium hydroxyapatite (Sr-HA), confirmed to enhance bioactivity in the PEKK. Osseointegration was found to occur in both implant groups, with more rapid bone formation and maturation in the experimental group at both periods of healing. The present study evaluated the bone response of implants coated with Strontium hydroxyapatite (Sr-HA) were better than those in the control and composite group at 2 weeks and Sr-HA/PEKK composite is better at 6 weeks. So that the PEKK with added SR HA as composite or coating achieved better osseointegration than pure PEKK which is well suited for dental and orthopaedic implants.

Reference

1. Ammann P, Badoud I, Barraud S, Dayer R, Rizzoli R. Strontium ranelate treatment improves trabecular and cortical intrinsic bone tissue quality, a determinant of bone strength. Journal of Bone and Mineral Research. 2007;22(9):1419-25.
2. Brånemark R, Öhrnell L-O, Nilsson P, Thomsen P. Biomechanical characterization of osseointegration during healing: an experimental in vivo study in the rat. Biomaterials. 1997;18(14):969-78.
3. Buser D, Nydegger T, Oxland T, Cochran DL, Schenk RK, Hirt HP, et al. Interface shear strength of titanium implants with a sandblasted and acid-etched surface: a biomechanical study in the maxilla of miniature pigs. Journal of Biomedical Materials Research: An Official Journal of The Society for Biomaterials, The Japanese Society for Biomaterials, and The Australian Society for Biomaterials. 1999;45(2):75-83.
4. Choy KL, Schnabelrauch M, Wyrwa R. Bioactive coatings. Biomaterials in Clinical Practice: Springer; 2018. p. 361-406.
5. Christensen GJ. Misch's Contemporary Implant Dentistry. LWW; 2019.

6. Costa de Almeida C, Sena LÁ, Pinto M, Muller CA, Cavalcanti Lima JH, Soares GdA. In vivo characterization of titanium implants coated with synthetic hydroxyapatite by electrophoresis. Brazilian Dental Journal. 2005;16(1):75-81.
7. D'Ercole S, Cellini L, Pilato S, Di Lodovico S, Iezzi G, Piattelli A, et al. Material characterization and Streptococcus oralis adhesion on Polyetheretherketone (PEEK) and titanium surfaces used in implantology. Journal of Materials Science: Materials in Medicine. 2020;31(10):1-11.
8. Dahl S, Allain P, Marie P, Mauras Y, Boivin G, Ammann P, et al. Incorporation and distribution of strontium in bone. Bone. 2001;28(4):446-53.
9. Dai J, Cheng N, Miron RJ, Shi B, Cheng X, Zhang Y. Effect of decreased implant healing time on bone (re) modeling adjacent to plateaued implants under functional loading in a dog model. Clinical oral investigations. 2014;18(1):77-86.
10. Doornewaard R, Glibert M, Matthys C, Vervaeke S, Bronkhorst E, De Bruyn H. Improvement of quality of life with implant-supported mandibular overdentures and the effect of implant type and surgical procedure on bone and soft tissue stability: a three-year prospective split-mouth trial. Journal of Clinical Medicine. 2019;8(6):773.
11. Elias CN, Oshida Y, Lima JHC, Muller CA. Relationship between surface properties (roughness, wettability and morphology) of titanium and dental implant removal torque. Journal of the mechanical behavior of biomedical materials. 2008;1(3):234-42.
12. El-nawawy T, Swailem AM, Ghorab D, Nour S. Solubility enhancement of olmesartan by utilization of solid dispersion and complexation techniques. Int J Novel Drug Deliv Tech. 2012;2(4):297-303.
13. Escanero J. EFFETS DES DIFFERENTS METABOLITES DE LA VITAMINE D3 ET DE LA CONCENTRATION CALCIQUE SUR L'ABSORPTION INTESTINALE DU STRONTIUM. 1976.
14. Fabbri P, Messori M. Surface modification of polymers: chemical, physical, and biological routes. Modification of Polymer Properties: Elsevier; 2017. p. 109-30.
15. Goldstein JI, Newbury DE, Michael JR, Ritchie NW, Scott JHJ, Joy DC. Scanning electron microscopy and X-ray microanalysis: Springer; 2017.
16. Hamdi DA, Jiang Z-T, No K, Rahman MM, Lee P-C, Truc LNT, et al. Biocompatibility study of multi-layered hydroxyapatite coatings synthesized on Ti-6Al-4V alloys by RF magnetron sputtering for prosthetic-orthopaedic implant applications. Applied Surface Science. 2019;463:292-9.
17. Hamdi DA. Deposition Hydroxyapatite/Titania Composite on Ti-6Al-7Nb Alloy for Human Body Implants. Al-Nahrain Journal for Engineering Sciences. 2018;21(4):467-72.
18. Hussein AA. Fabrication and Characterization of Advanced Blend Polymer Nanocomposites for Human Bone Structural Applications: Ph. D. Thesis; 2017.
19. Jeong O-C, Park J-W, Lee J-M, Suh J-Y. Effects of a Nanostructured Calcium Titanate Coating on the Osseointegration of Blasted Endosseous Implants in Rabbit Tibiae. 대한치주과학회: 학술대회논문집. 2006:105-6.

20. Kligman S, Ren Z, Chung C-H, Perillo MA, Chang Y-C, Koo H, et al. The impact of dental implant surface modifications on osseointegration and biofilm formation. Journal of Clinical Medicine. 2021;10(8):1641.
21. Kokubo T, Takadama H. How useful is SBF in predicting in vivo bone bioactivity? Biomaterials. 2006;27(15):2907-15.
22. Kumar M, Gnansounou E, Thakur IS. Synthesis of bioactive material by sol–gel process utilizing polymorphic calcium carbonate precipitate and their direct and indirect in-vitro cytotoxicity analysis. Environmental Technology & Innovation. 2020;18:100647.
23. Kurtz SM, Devine JN. PEEK biomaterials in trauma, orthopedic, and spinal implants. Biomaterials. 2007;28(32):4845-69.
24. Liao C, Li Y, Tjong SC. Polyetheretherketone and its composites for bone replacement and regeneration. Polymers. 2020;12(12):2858.
25. Ma R, Tang T. Current strategies to improve the bioactivity of PEEK. International journal of molecular sciences. 2014;15(4):5426-45.
26. Ma R, Weng L, Fang L, Luo Z, Song S. Structure and mechanical performance of in situ synthesized hydroxyapatite/polyetheretherketone nanocomposite materials. Journal of sol-gel science and technology. 2012;62(1):52-6.
27. Mark HF, Kroschwitz JI. Encyclopedia of polymer science and engineering1985.
28. Mittal V. Polymer nanotubes nanocomposites: synthesis, properties and applications: John Wiley & Sons; 2014.
29. Moursi AM, Winnard AV, Winnard PL, Lannutti JJ, Seghi RR. Enhanced osteoblast response to a polymethylmethacrylate–hydroxyapatite composite. Biomaterials. 2002;23(1):133-44.
30. Najeeb S, Khurshid Z, Matinlinna JP, Siddiqui F, Nassani MZ, Baroudi K. Nanomodified peek dental implants: Bioactive composites and surface modification—A review. International journal of dentistry. 2015;2015.
31. Osman RB, Swain MV. A critical review of dental implant materials with an emphasis on titanium versus zirconia. Materials. 2015;8(3):932-58.
32. Ramanaiah K, Prasad AR, Reddy KHC. Effect of fiber loading on mechanical properties of borassus seed shoot fiber reinforced polyester composites. Journal of Materials and Environmental Science. 2012;3(2):374-8.
33. Reed SJB. Electron microprobe analysis and scanning electron microscopy in geology: Cambridge university press; 2005.
34. Roeder RK. Bioactive polyaryletherketone composites. PEEK biomaterials handbook: Elsevier; 2019. p. 203-27.
35. Saraswati, P. A. I. ., Gunawan, I. M. K., & Budiyasa, D. G. A. (2021). Overview of glomerulus filtration in type 2 of diabetes mellitus at Sanjiwani Gianyar hospital year of 2018-2019. International Journal of Health & Medical Sciences, 4(1), 50-55. https://doi.org/10.31295/ijhms.v4n1.726
36. Suryasa, I. W., Rodríguez-Gámez, M., & Koldoris, T. (2021). Get vaccinated when it is your turn and follow the local guidelines. International Journal of Health Sciences, 5(3), x-xv. https://doi.org/10.53730/ijhs.v5n3.2938
37. Toth JM, Wang M, Estes BT, Scifert JL, Seim III HB, Turner AS. Polyetheretherketone as a biomaterial for spinal applications. Biomaterials. 2006;27(3):324-34.
38. Vaezi M, Black C, Gibbs DM, Oreffo RO, Brady M, Moshrefi-Torbati M, et al. Characterization of new PEEK/HA composites with 3D HA network fabricated by extrusion freeforming. Molecules. 2016;21(6):687.