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Experimental Evaluation and Finite Element Analysis of Stress Distribution in 3D-Printed Dental Implants to Validate the Optimal Thread Pitch

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ABSTRACT

Objective: As an alternative method of prosthetic rehabilitation, the dental implant serves as one of the solutions that may be used to restore a missing tooth over a lengthy period of time. In order to achieve stress concentration in 3D printed 30% CFR PEEK dental implants, the finite element approach and the experimental photoelasticity test are applied. This is done in order to find the optimal thread pitch for a 3D printed 30% CFR PEEK implant and its impact on the bone implant interface. Materials and methods: Three-dimensional models were generated for the one-piece implant and bone structures. The models were created by introducing variations of 0.8mm, 1mm, and 1.2mm in the thread pitch while maintaining a fixed implant length of 13mm. SolidWorks software was employed for the creation of these models. Subsequently, the stress distribution of the models was simulated under axial load using ANSYS software. An experimental model was created utilizing 3D printing technology, and further experimental tests were conducted to assess the stress concentration in dental implants-bone interfaces. These evaluations were performed using the photoelasticity test method. Results: As a result of the findings, it seems that the implant, cortical, and cancellous bones all exhibit different levels of stress intensity. A thorough analysis of the stress intensity is used to establish the optimal configuration for the pitch of the components and the behavior of 3D printed implant in cancellous bone. Conclusions: After careful consideration, it has been shown that the current finite element model adequately forecasts the stress concentration pattern of dental implants. In light of the fact that the findings of the FEM test are more accurate than those of the photoelasticity test, it is recommended that computation techniques be used in medical practice since they have tremendous potential for new research. This research suggested that the optimum ranges for the length and pitch of the 3D printed 30% CFR PEEK implant are determined to be 13mm and 0.8mm, respectively and a low implant thread pitch results in a reduction in stress concentration at the implant - cancellous bone interface.

1. INTRODUCTION

In recent days, dental implants have emerged as a prevalent treatment modality in dentistry for the restoration of a missing tooth. Although dental implants have a generally high likelihood of success, difficulties might arise due to the influence generated by mechanical stimulation and the differences in structure between natural teeth and prostheses [1]. The degree of rigidity that implants exhibit, which includes intricate cellular and molecular processes taking place at the interface between the bone and the implant, is the main factor influencing osseointegration [2]. Although dental implants have shown efficacy as a therapeutic intervention, their potential for failure may be attributed to several causes. The transfer of stress to the adjacent bone has a significant impact on the osseointegration of the implant. The effective osseointegration of dental implants is closely tied to a number of parameters, counting the contours of the implant, its design, its surgical method, and the quality of the bone in the jaw. Thread pitch and implant materials have more significance in clinical settings since they may impact the speed of implantation and operational ease [3, 4].

Utilizing both experimental and mathematical investigation approaches, researchers have investigated the biomechanical properties of dental implants [5]. Researchers Li and Zaparolli employed primarily qualitative photoelastic study to examine the stress distribution of full dentures. Li's research concentrated on establishing the best range of implant diameter and implant length for type II bone [6, 7]. In order to examine the stress concentration in screws and the bone tissue that surrounds four implants, Verri and colleagues developed three-dimensional models [8]. When it comes to reduction of bone stress and developing the stability between the implant and the abutment, the length of the implant and thread pitch are a more important factor than the diameter of the implant [7, 8]. When it comes to length, the best range is between 8 and 13 millimeters, which corresponds to the usual length of roots. In contrast, implants with a diameter of 7 millimeters had the greatest probability of failing in recent years, as compared to implants with a diameter of 8.5 millimeters, 10 millimeters, and 11.5 millimeters. There was no association observed between the length of the implant and early mobility, and the degree to which success rates may be raised by increasing the length of the implant is only modestly possible [9, 10]. The distribution of load to the adjacent bone is influenced by various characteristics, including the length, diameter, pitch, and factors. Threads are employed in order to optimize the preliminary bonding, enhance the initial stability, increase the surface area of the implant and promote the elimination of stress at the interface. Furthermore, it is possible to manipulate thread geometric parameters in order to alter the operational thread area and impact the distribution of load system of the implant. Thread pitch is regarded as an important factor among the various thread characteristics due to its clinical importance in an operation. It has the potential to impact life of the implant. [5-10].

The progressive finite element method is applied in order to evaluate the biomechanical behavior of dental implants. The study of dental implants has been aided by the development of sophisticated methods for dental arch form determination in dental CBCT images as well as 3D finite element studies [11]. Utilizing FE formulae, Brune et al. [12] investigated the distribution of bone stress around an implant crown that included a single tooth. During the course of dental implant research, Ueda et al. used finite element modeling to optimize the diameter and length of titanium implants and mandibles for bone quality. Implants in the teeth might be beneficial for individuals with alveolar bone resorption, depending on the height and thickness of the teeth [10-12].

In additive manufacturing, layers of material are stacked to build components. Vat photo polymerization (VPP), powder bed fusion (PBF), material extrusion (MEX), and others are 3D printing categories. Additive manufacturing technology has considerable uses in oral implantology. Surgical guidelines, implant casts, bespoke dental implants, and implant-support structure are made [13, 14]. In oral implantology, additive manufacturing methods such as stereolithography, digital light processing, fused deposition modeling, direct metal laser sintering, selective laser melting, and electron beam melting are often employed. Each technology has unique benefits and is chosen depending on application needs [14]. Fused deposition modeling (FDM) is extensively utilized in medical and dental equipment, whereas powder bed fusion (PBF) is the most popular metal-printing process in dentistry. Additive manufacturing technologies have transformed oral implantology by directly fabricating complicated things from computer-aided design models [15, 16].

Through the use of finite element modeling, the purpose of this research is to determine the stress distribution of dental implants when subjected to axial and oblique loads [12]. The evaluation of the impact of thread pitch and implant length on stress distribution is the primary focus of this study. Additionally, the optimal biomechanical parameters of the implant are targeted for investigation. It has been observed by the authors that the majority of research conducted in this area has concentrated on specific and distinct effects of implant characteristics on stress distribution. The FEM is used in the research to conduct an analysis of the suggested design, and the findings are correlated to those obtained by the experimental photoelasticity approach. In light of these findings, it is anticipated that the quality of dental implants would increase. Under axial and oblique pressures, the analysis is one of a kind since it focuses on analyzing the distribution of stress and the sensitivity of the material [17, 18].

The most commonly used material for dental implants is titanium and its alloys. This is because titanium has excellent biocompatibility because it is well-tolerated by the body and does not cause an adverse reaction. Additionally, titanium has distinguished mechanical properties, counting high strength, low density, and resistance to corrosion and wear. Titanium dental implants are typically placed into the jawbone and left to osseointegrate, or fuse with the bone, over a period of several months. Once the implant is fully integrated, a prosthetic tooth or bridge is attached to the implant [19]. In recent years, other materials, such as zirconia and ceramics, have been developed as alternatives to titanium. Zirconia is a ceramic material that has been shown to have excellent biocompatibility and strength, making it a promising alternative to titanium. Ceramic materials are also biocompatible, and they have the advantage of being tooth-colored, making them a good option for patients who want a more natural-looking implant [20]. The use of polymers in dental implantation provides versatility, ease of processing, and cost-effectiveness. They offer suitable mechanical properties, biocompatibility, and aesthetics for specific dental implant applications. However, it’s important to note that the selection of the polymer should be based on the specific requirements of the case, and the long-term clinical studies are necessary to evaluate their performance and longevity in dental implantation.

- **Polyetheretherketone (PEEK):** PEEK is a high-performance polymer that exhibits excellent mechanical properties, biocompatibility, and chemical resistance. It has been used in different dental applications, including dental implant components and prosthetic frameworks.
- **Polymethyl Methacrylate (PMMA):** PMMA is a widely used polymer in dentistry, particularly in the fabrication of temporary prostheses and denture bases. It is known for its aesthetics, ease of processing, and cost-effectiveness.
- **Polyurethane (PU):** PU is a versatile polymer that has been used in dental implantation for applications such as temporary implant prostheses. It offers good biocompatibility and can be easily molded and customized.
- **Polyethylene (PE):** PE is a thermoplastic polymer that has been used in dental implantation for various purposes, including temporary implant prostheses. It is known for its low cost and ease of fabrication.
- **Polycarbonate (PC):** PC is a strong and impact-resistant polymer that has been used in dental implantation for temporary prostheses and surgical guides. It offers good mechanical properties and ease of processing.
- **Polyvinyl Chloride (PVC):** PVC is a widely used polymer in various dental applications, including temporary implant prostheses and denture bases. It is known for its versatility, cost-effectiveness, and ease of fabrication.
- **Polyethylene Terephthalate (PET):** PET is a strong and rigid polymer that has been used in dental

implantation for temporary prostheses and implant components. It offers good mechanical properties and chemical resistance.

The purpose of dental implantation using 30% CFR-PEEK material is to provide an alternative to traditional dental implant materials, such as titanium, that can improve the overall performance and longevity of dental implants. 30% CFR-PEEK is a composite material made of carbon fibers and poly ether ether ketone, which has been shown to have several advantages over other dental implant materials. One advantage of 30% CFR-PEEK is its high strength and durability, which can reduce the risk of implant failure and increase the lifespan of the implant. Additionally, 30% CFR-PEEK has a lower modulus of elasticity than titanium, which means it can absorb more of the forces generated during biting and chewing, reducing the risk of bone loss around the implant [21, 22]. Another advantage of 30% CFR-PEEK is its biocompatibility, which means it is well-tolerated by the body and does not cause an adverse reaction. In fact, studies have shown that CFR-PEEK can promote bone growth and osseointegration, which can lead to improved long-term stability of the implant. CFR-PEEK also has the advantage of being radiolucent, meaning it does not interfere with x-rays or other imaging techniques, which can make it easier for dentists to monitor the health and stability of the implant over time [22].

This research used the Finite Element technique to create the design for the mandible and an implant. Additionally, the significance of 3D printing in the manufacturing of implants and the use of 30% CFR material were examined. The photoelasticity technique is used to experimentally assess the stress intensity. Moreover, there is a dearth of extensive study regarding the influence of pitch and other geometrical variables on stress distribution in Dental implants made of 30% CFR PEEK. Hence, the aim of this research is to investigate the influence of various thread pitch and geometrical properties on stress distribution in cortical, cancellous bone for 30% CFR PEEK 3D printed implants.

2. MATERIALS AND METHODS

2.1 CAD model

Dental implants have no standardized method of design, as every individual implant has its own various factors. Dental implants are a suitable and effectual solution for replacing missing teeth. They are designed to function and resemble natural teeth, providing stability, durability, and aesthetics. [11, 12] The design of a dental implant involves several key components that work together to create a successful implant restoration. Here are the main elements of a dental implant design, implant abutment, prosthetic abutment, prosthetic restoration(crown), thread design, surface treatment, implant size and shape [17, 18].

It's important to note that dental implant designs may vary among different manufacturers and implant systems. Dentists and oral surgeons evaluate individual patient needs and select appropriate implant designs and components to ensure the best possible outcome for each case.

In this research, Solidworks (SOLIDWORKS EDU Edition 2022-23)- a 3D modeling software is used to design a one-piece implant that is fabricated by the additive manufacturing process. The implant's major factor is to minimize the stress concentration in the cancellous bone and also near the tooth. The implant body length was fixed at 13mm, diameter of the implant was 6mm and the thread pitch was varied between 0.8mm, 1.0mm, and 1.2mm to determine the low stress concentration in the implant. (Manufacturer: www.mis-implants.com)

Mostafa Pirmoradian experimented with his designed implant with implant length from 8mm to 13mm and thread pitches ranging from 0.6mm to 1mm. Assembled implant view shown in Figure 1 and implant length and pitch value mentioned in Table 1.

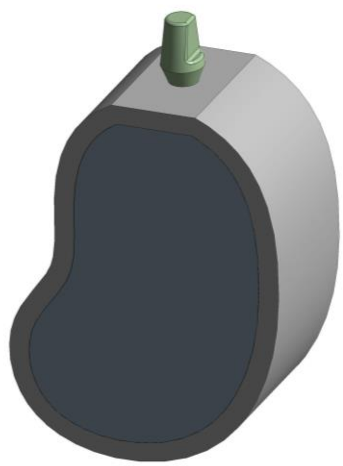


Figure 1. Assembled view of bone-implant model

Table 1. Variable parameter of the thread pitch in 6mm diameter implants

Length of the Body Implant (mm)	Thread Pitch (mm)
13	0.8
13	1.0
13	1.2

2.2 Selection of materials

CFR-PEEK (carbon fiber reinforced polyetheretherketone) is an emerging material for dental implantation that has shown promise in several areas. It has favorable characteristics like biocompatibility, Strength and durability, Osseointegration, Radiolucency and Lightweight [23]. Overall the scope of CFR-PEEK as a dental implantation is promising and it has the potential to provide patients with a durable, biocompatible, and stable implant option that can improve their oral health and quality of life. Using 30% CFR-PEEK as a dental implant material has shown promising results in terms of biocompatibility, strength, durability, and thermal properties. Figure 2 shows 30% CFR PEEK material properties.

Additionally, 30% CFR-PEEK is light weight, reducing the stress on the surrounding bone and improving the overall comfort of the implant for the patient. Its use is still relatively new in dentistry. Overall, the use of 30% CFR-PEEK shows potential as a viable alternative to traditional materials such as titanium and zirconia in the long term. Table 2 shows the material; and its property range [23-25]. Properties of different materials taken from literature [4, 20, 23-25].

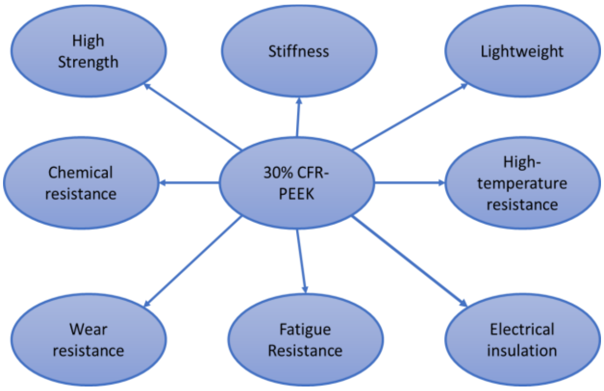


Figure 2. 30% CFR-PEEK properties

Table 2. Material properties

Properties	Titanium	Zirconia	CFR-PEEK
Biocompatibility	●	●	●
Strength and durability	●	●	●
Osseointegration	●	●	●
Radiopacity	●	●	●
Aesthetics		●	
Thermal Properties	●	●	●
Light Weight		●	●

Table 3. Comparison of properties

Properties	Titanium	Zirconia	30%CFR-PEEK
Poisson's ratio	0.34-0.38	0.3-0.31	0.35-0.37
Young's Modulus	100-120GPa	200-240GPa	3-4GPa
Tensile Strength	500-1100MPa	900-1200MPa	90-100MPa

Table 3 shows the comparison of material properties, where we can see that these materials have their own unique benefit and disadvantages, and the choice of materials will depend on several factors, including the patient's individual needs and preferences, the location of the implant, the design of the implant and the dentist's experience and expertise [26, 27].

2.3 Finite element analysis

Finite element analysis is a widely used computational method for analyzing the stress distribution, deformation, and load transfer within dental implants and surrounding structures.

Table 4. Node and element details for FE analysis

	Node	Element
0.8mm pitch	983205	572638
1mm pitch	965065	562076
1.2mm pitch	974784	568354

It involves discretizing the implant and surrounding bone into small elements and applying mathematical equations to stimulate their behavior under different loading conditions. FEA can help predict stress concentrations, identify potential implant failure points, and optimize implant designs [27, 28].

2.3.1 Material meshing properties

With the aim of making the computation process more comprehensible, the materials used in this research were treated to be isotropic, linear elastic, and homogeneous. The properties of various elements are given in the table. The implant is strongly entrenched in the bone base, and it makes a tenacious screwed surface at the juncture with the mandibular bone. A similar kind of acquaintance at the bone-implant interface is developed during the simulation study. The Implant-Bone model is discretized with 10 node quadratic tetrahedron elements for FE analysis. Node and element details are given in Table 4. The Ansys workbench (ANSYS 20.0 R1 software) is employed to analyze stress concentrations at bone-implant interface.

2.3.2 Loading conditions

Bone-implant model was constrained in all directions at nodes, and an axial load of three different loads (50kg, 75kg and 100kg) was applied to the middle point at the center of the model. Stress concentrations on the implant and bone interface were analyzed by Ansys software.

2.4. Experimental method

2.4.1 Additive manufacturing

Dental implant fabrication using AM process (additive manufacturing) through FDM (fused deposition modeling) technology is a relatively new and evolving area. FDM is a popular form of 3D printing that involves the deposition of thermoplastic materials layer by layer [29].

The process begins with creating a digital design or a 3D model of the dental implant using computer-aided design (CAD) software. The design captures the specific requirements of the patient's dental anatomy, including dimensions and shape. A slicer is an essential software tool used in additive manufacturing [29, 30]. We used a Prusa slicer for slicing. Sliced component is shown in Figure 3. It plays a crucial role in converting a 3D model into G code. The 3D model is filled with 100% infill, and we chose the flat landscape orientation on the bed and printed with Funmat-HT Modified Machine.

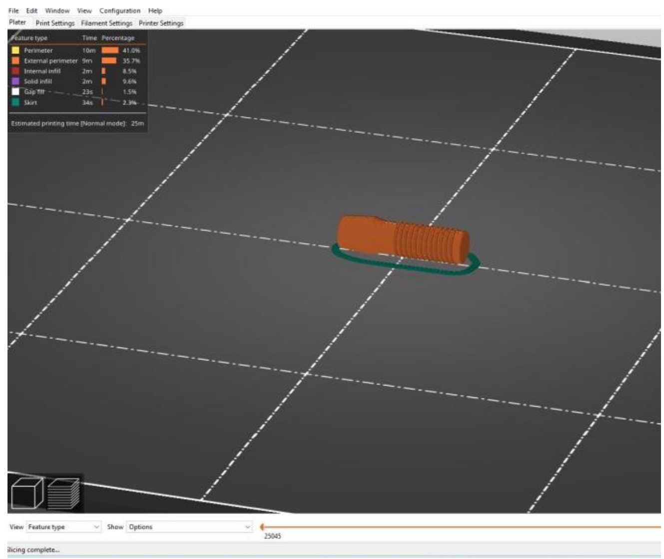


Figure 3. 3D implant model with slicing

The 30% CFR-PEEK filament was loaded into the 3D printer nozzle, which heats the filament at 450°C, liquefies it, and deposits it layer by layer onto a build platform according to the digital design. The printer nozzle moves along the predefined path, creating a solid object. The bed of the printer is heated constantly and maintained at 160°C. After printing, the required post processing method is taken to get the final implant.3D printed component shown in Figure 4, Figure 5 and Figure 6

Figure 4. 3D printed implant with 0.8mm thread pitch

Figure 5. 3D printed implant with 1mm thread pitch

Figure 6. 3D printed implant with 1.2mm thread pitch

The adoption of FDM for dental implant fabrication is still evolving, and research and development efforts are ongoing to address the challenges associated with this technology. Dentists, oral surgeons, and dental laboratories can work together to assess the suitability of FDM and determine the best manufacturing methods for each patient's specific needs.

2.4.2 Photoelasticity method and setup

Photoelasticity is an optical technique used to study and analyze the stress concentration and strain within transparent materials. It provides a visual representation of stress patterns by utilizing the principle of birefringence, which is the phenomenon of light splitting into two orthogonally polarized waves when passing through certain materials under stress.

A photoelasticity experimental setup involves the following:

- **Light Source:** A light source is used to provide illumination for the photoelastic material. This can be a white light source, or a monochromatic light source.
- **Polarizer:** A polarizer is placed between the light source and the photoelastic material. It polarizes the light, allowing only a specific polarization direction to pass through.
- **Photoelastic Material:** The photoelastic material, typically a transparent or translucent polymer or glass, is the material being tested. It exhibits birefringence when subjected to mechanical stress.
- **Mechanical Loading:** The photoelastic material is loaded with mechanical forces or stresses applied in a controlled manner. This can be achieved using a mechanical loading system, such as a load frame or specialized fixtures, to apply forces or deformations to the material.
- **Analyzer:** An analyzer is positioned between the photoelastic material and the observation system. The analyzer helps analyze the altered polarization state of light that passes through the stressed material.
- **Observation:** An observation system, such as a camera or a microscope, is used to capture the fringe patterns formed by the altered light passing through the stressed photoelastic material.

The photoelastic material is positioned within a polariscope, comprising a polarizer and an analyzer, in order to conduct a photoelasticity test. The polarizer induces polarization of the light, which is subsequently transmitted through the photoelastic material under stress. The refractive indices of light vary as it traverses the substance, contingent upon the stress distribution present within the material. The analyzer is responsible for examining the emerging light and subsequently identifying the ensuing fringe patterns [31, 32].

These fringe patterns represent areas of different stress levels and orientations within the material. By analyzing it, one can gain insights into stress concentrations, areas of high strain, and load distribution within the material or structure.

In a two-dimensional transparent model, two major stresses represent the highest and lowest levels of direct stress. When light waves travel, the difference in propagation velocities caused by relative retardation leads to the occurrence of maximum shear stress. The retardation is influenced by the thickness of the model and the material's susceptibility to photoelasticity. Most materials exhibit a consistent relative retardation across all wavelengths [32].

While photoelasticity is not commonly used specifically for dental implantations, it can be applied to assess the stress patterns around dental implants in certain research or experimental settings. It is primarily used in the research and development stages to investigate and optimize implant designs. A model base for dental implants is created using a transparent or translucent material, like acrylic. A rectangular block of acrylic sheet as a birefringence material with required thickness and 3D printed one-piece implant utilized for this experiment. Photoelastic materials exhibit changes in polarization and color when subjected to stress, allowing for the visualization of stress patterns. Polarized light is directed onto the photoelastic material. As the light passes through the material and encounters stress, it is altered in polarization and intensity. Photoelasticity experimental setup shown in Figure 7.

Figure 7. Photoelasticity experimental setup

The captured images or patterns by using a polariscope reveal the stress concentration and intensity around the dental implant and the surrounding bone. The captured fringe patterns are interpreted to understand the stress concentration, concentration points, and potential areas of concern. This analysis can provide insights into the biomechanical behavior of the implant and aid in optimizing its design and placement.

A Relationship between R (the relative retardation) and ($\sigma1-\sigma2$) (difference between the principal stresses) is given below [33]:

$$R=Ct(\sigma1-\sigma2) \quad (1)$$

Thickness of the acrylic sheet(t): 10mm

C is a constant of the material

Fringe material constant value for Acrylic or PMMA or Plexiglass($f\sigma$): 130N/mm

Elastic modulus(GPa)=1.8-3.1

Poisson ratio =0.35-0.4

Equation used for photoelastic analysis

$$\text{Stress intensity}=\sigma1-\sigma2=(N_{avg}*f\sigma)/t \quad \text{MPa} \quad (2)$$

N is the fringe order

3. RESULTS AND DISCUSSION

3.1 Evaluation of FEA method

The challenges associated with conducting experiments on dental implants, in addition to the successful outcomes of 3D finite element (FE) modeling of dental implants under both symmetrical and unsymmetrical pressures induced by chewing forces, have prompted efforts to simulate dental implant procedures. Assessing the transmission of force at the interface between the bone and implant is a crucial part of analyzing the load, which determines the outcome of dental implants [34]. Stress intensity, a suitable and commonly used parameter to evaluate materials that can be easily deformed, is employed in finite element analysis to provide a concise representation of the total stress condition at a specific location. Stress intensity is a scalar quantity that is determined based on the separate stress elements. Stress intensity values are employed to compute stress concentration in both the bone and the one-piece implant unit across all models [33, 34].

A strong link exists between the stress intensity in cancellous bone, cortical bone, and the implant interfaces. Nevertheless, it is important to note that it is influenced by changes in thread pitch. Furthermore, when taking into account the cancellous bone, cortical bone, and implant, the stress intensity is minimized when the thread pitch is 0.8mm, length kept 13mm for three different load conditions (50kg, 75kg and 100kg). Furthermore, the findings indicate that the highest stress intensity in cancellous bone occurs at a length of 13mm, pitch of 1.2mm for three different load conditions. Moreover, the attainment of the lowest stress values takes place at 0.8mm pitch. Furthermore, it is noted that the implants having increased pitch value of 1.2mm exhibit the highest stress levels inside the cancellous bone. The findings indicate that longer implants with 0.8mm pitch result in reduced stress intensity in the cancellous bone as compared to 1.2mm thread pitch. The implant was fabricated by using an additive manufacturing process (Funmat-HT modified FDM printer) with 30% CFR PEEK material. These findings are compared with results of titanium and its alloys and zirconia material. the results of Jung and Yoon [35], suggesting that lengthening the length of the implant and thread pitch with 0.8mm or less than that is important to enhance the contact area between the implant and bone, hence reducing stress intensity on the bone.

The results of Table 5 indicate that out of the nine analyses conducted to determine stress intensity for cancellous bone, the stress intensity for a 13mm length and 0.8mm pitch, 1mm pitch and 1.2mm pitch implants are shown in Figures 8-10. These figures illustrate the stress intensity contours for cancellous bone.

The findings indicate that the implant - cancellous interface combination experiences the highest level of stress for higher pitch value regardless of the load applied. The transitional stress values pertain specifically to the cortical bone, particularly at the point where it comes into contact with the neck of the implant. Furthermore, the cancellous bone exhibits the lowest magnitudes of stress as a result of its comparatively low elastic modulus. The findings are consistent with the research conducted by Pirmoradian et al. [33].

To evaluate the resulting stresses caused by employing axial load and to get more accurate deductions for determining the optimal values of thread pitch from the data provided in Table 5, 50N,75N and 100N axial force is applied to the models. The stress intensity profile in the cancellous bone under axial load are shown in Figures 8-10, respectively. Moreover, Figures 8-10 demonstrate that the highest level of stress intensity in the cancellous bone occurs at the termination of the cancellous bone cavity, where it comes into interaction with the prosthetic head. This finding aligns with the results reported by Achour et al. [36].

Table 5. FEA Results

Implant Length (mm)	Pitch (mm)	Load Applied(kg)	Force (N)	Stress Intensity (MPa) FEA(Avg)
13	0.8	50	490.5	1.1903
13	0.8	75	736.75	1.5929
13	0.8	100	981	2.0374
13	1.0	50	490.5	1.3391
13	1.0	75	736.75	1.7519
13	1.0	100	981	2.1768
13	1.2	50	490.5	1.58
13	1.2	75	736.75	1.7099
13	1.2	100	981	2.2069

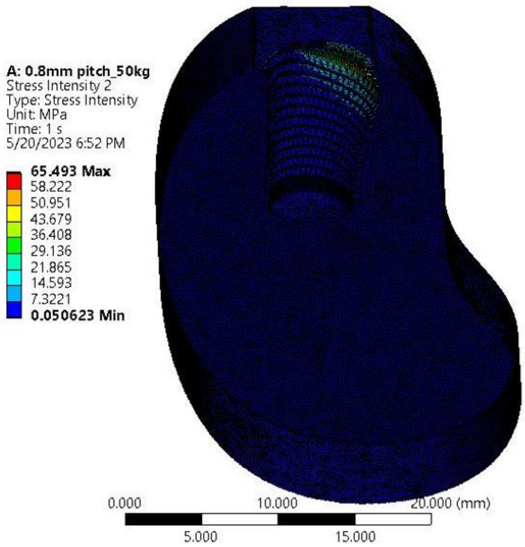


Figure 8. Stress intensity for 0.8mm pitch implant for 50kg load

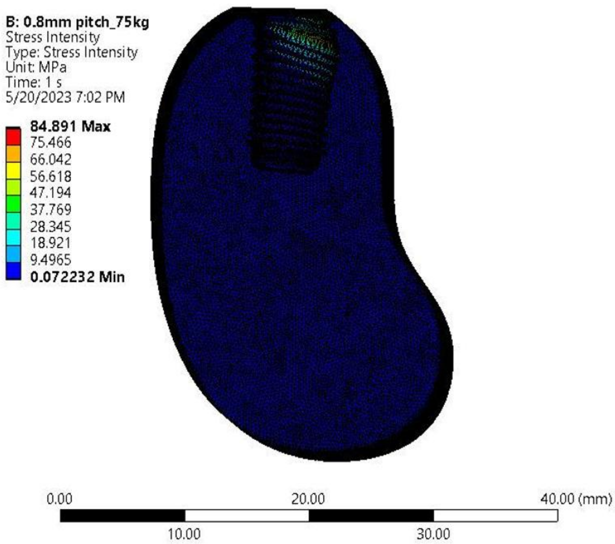


Figure 9. Stress intensity for 0.8mm pitch implant for 75kg load

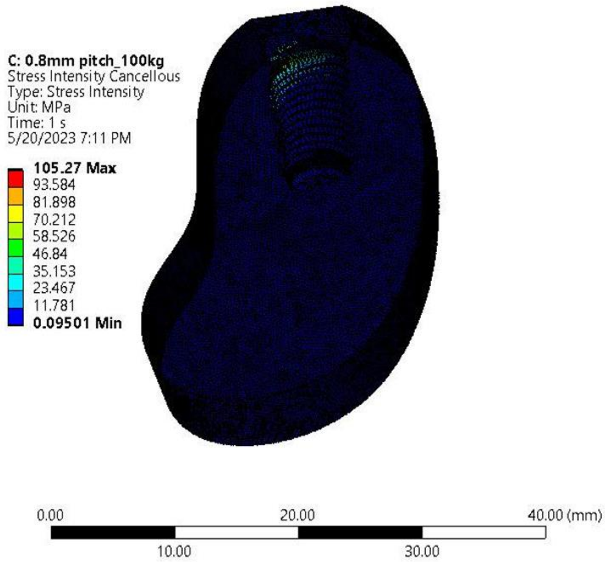


Figure 10. Stress intensity for 0.8mm pitch implant for 100kg load

3.2 Evaluation of photoelasticity test

In stress intensity, points wherein the variance among the primary stresses is a valid factor of f/t are going to appear black, whereas points in which this condition is not met would appear light. For the calculation of f/t, the magnitude of f is obtained via databases that provide fringe-stress ratios. The present prototype has an outcome of f equal to -700 lbf/in (-13000N/m). The chosen value for the prototype's thickness, t, is 10mm. The magnitude of f/t is determined to be -13MPa, which is a non-integer number. As a result, the specimen will exhibit luminosity. The stress intensity resulting from exploratory photoelastic research and finite element (FE) modeling of the plexi-glass is shown in Figures 11-13, respectively. The stress intensity shown in Figures 11 and 13 validates the agreement between the outcomes obtained from the photoelasticity technique and the finite element simulation. Furthermore, it is evident that the highest level of tension is concentrated in the cervical region and the base of the plexi block. Table 6 indicates that the fringe order for the dim red hue, as shown in Figures 11-13, is precisely. By putting the values f/t=-13MPa and N=0.7 into the stress intensity equation, we can calculate the difference between the primary stresses as σ 1-σ 2=-7.02MPa. Based on the application of a normal force, it may be inferred that σ 2 is equal to 7.02 megapascals (MPa). stress intensity for each model calculated and given in the Table 6. As per the result, 3D printed 30% CFR PEEK implant with 0.8mm thread pitch is having reduced stress concentration at the cancellous bone and implant region. This result is aligned with study by Pirmoradian et al. [18].

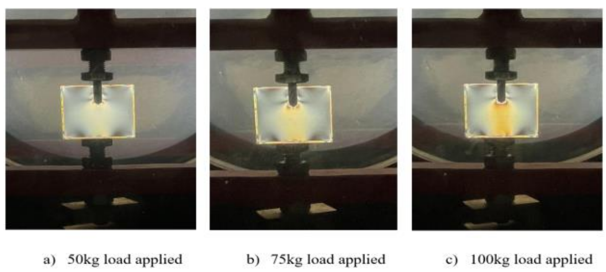
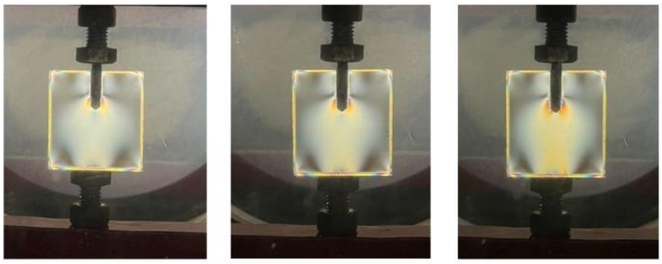
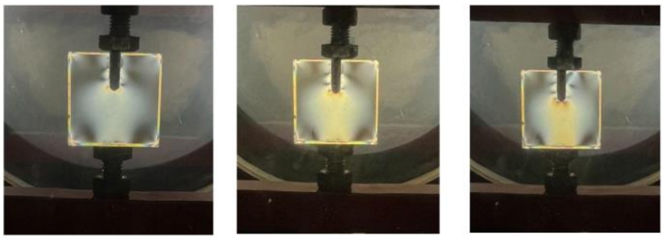


Figure 11. Stress distribution for a 0.8mm thread pitch



50kg load applied 75kg load applied 100kg load applied

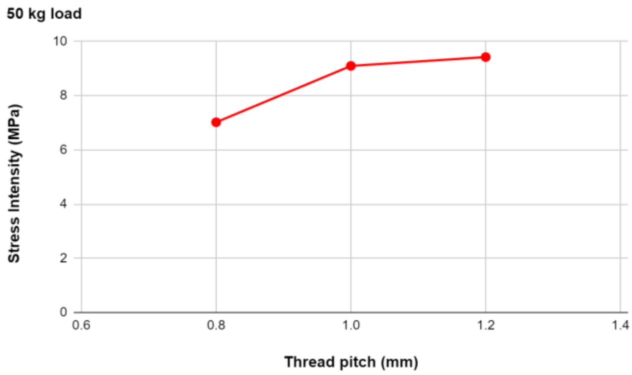
Figure 12. Stress distribution for a 1mm thread pitch



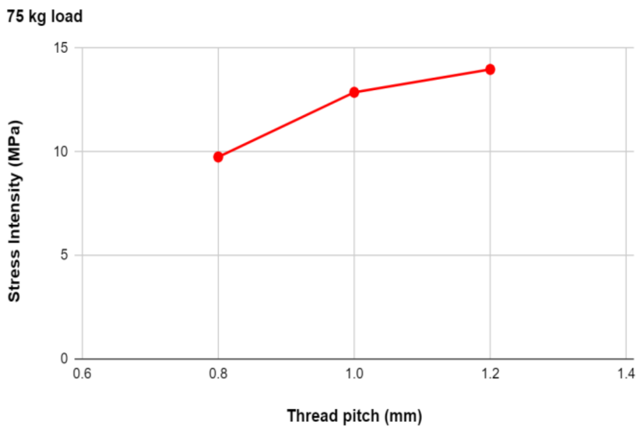
50kg load applied 75kg load applied 100kg load applied

Figure 13. Stress distribution for a 1.2mm thread pitch

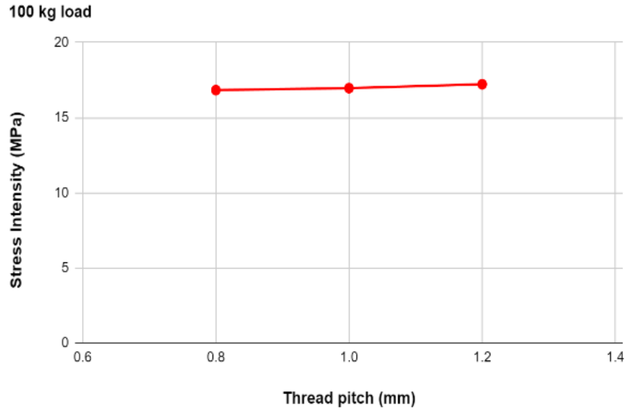
This research is conclude that among all the implants with 0.8 mm thread pitch and length 13mm has been identified as the system showing less stress intensity and even stress pattern therefore it has been proposed to be used in the design of experiments for the further development of new design as in the form of a new indigenous dental implant system. Results shown in Figure 14 and Figure 15 in graphical form.



(a) 50Kg load

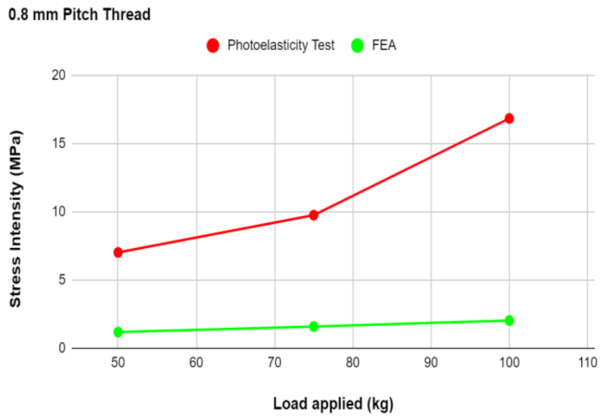


(b) 75Kg load

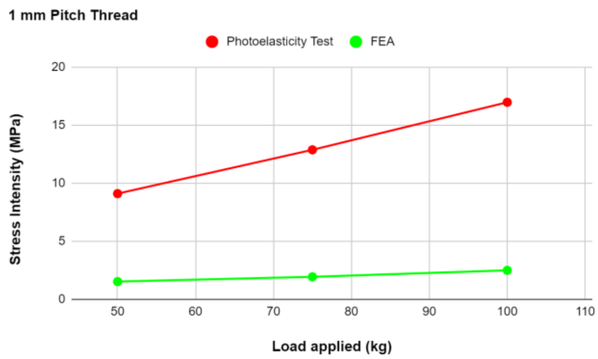


(c) 100Kg load

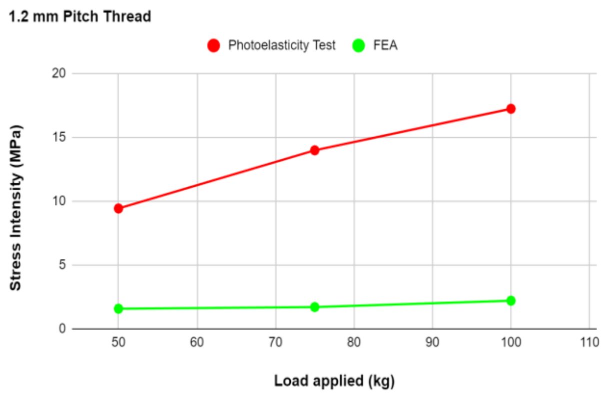
Figure 14. Thread pitch vs stress intensity by photoelasticity



(a) 0.8mm pitch



(b) 1mm pitch



(c) 1.2mm pitch

Figure 15. Comparison of FEA vs photoelasticity results

Table 6. Results of stress intensity by photoelasticity test

Depth of Implant (mm)	Pitch of the Thread (mm)	Load Applied (kg)	Force (N)	Fringe Order N	N1	N2	Navg	Stress Intensity (MPa)
13	0.8	50	490.5	1	0.28	0.8	0.54	7.02
13	0.8	75	736.75	1	0.6	0.9	0.75	9.75
13	0.8	100	981	1	1.38	1.22	1.295	16.835
13	1.0	50	490.5	1	0.8	0.6	0.7	9.1
13	1.0	75	736.75	1	0.9	1.08	0.99	12.87
13	1.0	100	981	1	1.39	1.22	1.305	16.965
13	1.2	50	490.5	1	0.9	0.55	0.725	9.425
13	1.2	75	736.75	1	1.03	1.12	1.075	13.975
13	1.2	100	981	1	1.41	1.24	1.325	17.225

4. CONCLUSIONS

This study used finite element models and actual photoelasticity experiments to investigate stress intensity in dental implants. The objective was to determine the ideal thread pitch of dental implants and impact of using 3D printed with 30% CFR PEEK implant in cancellous bone. An evaluation was conducted to compare the outcomes of the photoelasticity test with the FE simulation, revealing a high level of concurrence. The findings of this article may be enumerated as follows:

(1) The preference for 30% CFR-PEEK over 60% CFR-PEEK is mainly based on several factors like mechanical properties, biocompatibility, and biochemical reaction in human beings. Though addition of carbon fiber reinforcement enhances the mechanical properties of PEEK, such as strength and stiffness. However, increasing the fiber content to 60% can make the material too rigid and brittle, potentially compromising its ability to absorb and distribute forces in the oral environment. 30% CFR-PEEK strikes a balance between mechanical strength and flexibility, providing sufficient load-bearing capacity and resistance to fatigue.

(2) Recently, there has been a growing interest in using 30% CFR PEEK as a material for dental implants. Therefore, more investigation is necessary to get a deeper understanding of how different materials affect the distribution of stress in the bone-implant system, particularly when considering various design parameters.

(3) The research further determined that altering the implant material would have an impact on the region of stress concentration.

(4) Based on stress intensity analysis of cancellous bone using finite element computations and photoelastic process shows the optimum ranges for the length and pitch of the 3D printed 30% CFR PEEK implant are determined to be 13mm and 0.8mm, respectively.

(5) 3D printing in dental implants is a promising manufacturing method and it helps to customize the implant based on the need. Still vivo study is required to prove its effectiveness.

(6) The present research is subject to many limitations. In this work, the Finite Element Analysis (FEA) model was assumed to be homogeneous and isotropic. Nevertheless, the characteristics of living tissue are completely distinct; for example, bone exhibits transverse non-homogeneity. Furthermore, this study does not take into account the impact of the crown. Therefore, it is imperative to approach the findings of this investigation with caution, and it is crucial to take into account the limitations of this investigation when extrapolating the findings to clinical contexts.

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