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3D Dental Prosthetic Tooth Crown: Re-Modeling of Customized Tooth Crown using Additive Manufacturing and Synthesis of Bio-Compactible Tooth Filling

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Abstract:- This paper aims to shows, that what extent 3d printing can be used in dental laboratories and dental practices at present. It attempts to present a rational evaluation of today's application of 3d printing technology in the context of dental restoration. In addition, the article discusses future perspectives and examines the ongoing viability of traditional dental laboratory services and manufacturing processes. It also shows which expertise is needed for the digital additive manufacturing of dental restoration and a case report of prosthetic treatment built upon 3d technologies for manufacturing of dental restorations. We designed a customized 3D tooth cap using 3D printing technology. Rhinoceros and Solid work are the software is used to design and simulated a customized 3d tooth cap. Ultimaker Cura software and Ansys is used to slice and to test the mechanical simulation of the tooth cap in viable environment such that there is no miscible after the implantation. The 3D printing methodology used to print the prototype model is Fused Deposition Modeling (FDM). Bio-compactible tooth filling / tooth cement was prepared using beta tri-calcium phosphate, co-polymers like Pectin and poly vinyl pyrrolidine (PVP) as a promising biomaterial to enhance a cell growth in a suitable environment. The tooth filling/tooth cement slurry was characterized by FTIR and the anti-bacterial testing was carried out against E. coli, pseudomonas, C. albicans and S. aureus it exhibits an excellent inhibition zone. Thus, our primary study was concluded that the bio-ceramic tooth filling could be an ideal solution instead of tooth gum.

Keywords:- *Customized 3D Tooth Cap, Bio-Compatible, Bio-Materials, FDM, and Tooth Filling.*

I. INTRODUCTION

Teeth are the rigid portion of our body. It can become damaged over time, including tooth decay, low calcium level, and injuries. Cavities and dental decay are two of the most frequent health issues worldwide. Children, teens, and elderly persons are more susceptible. It may affect anybody with teeth, including newborns. Cavities are small gaps or holes in the hard surface of your teeth that are permanently damaged. Also known as tooth decay or caries, are caused by a number of reasons, including bacteria in the mouth, frequent eating, drinking sugary beverages, and not brushing your teeth thoroughly. It may get larger and injure deeper layers of your teeth, causing a lot of discomfort, infection, and tooth loss if not treated. Your best defense against cavities and tooth decay is regular dental appointments and proper brushing and flossing routines. Depending on the size and location of the cavity, different indications and symptoms appear. When a cavity is just getting started, you may not notice any symptoms at all. As the condition worsens, you may notice symptoms such as toothache, sensitive tooth, when we eat or drink something sweet, spicy, or cold, we may have minor to severe pain, teeth having noticeable pits or holes, as well as discolored teeth (brown, black). Plaque is a sticky, transparent film that covers your teeth. It's caused by a diet high in sweets and carbohydrates, as well as a lack of dental hygiene. When sugars and starches aren't removed from your teeth, bacteria feast on them and plaque forms. Plaque acids dissolve minerals in the hard outer enamel of your teeth and holes in the enamel as a result of this degradation. Bacteria and acid can enter the dentin layer of your teeth if sections of enamel have been worn away. This layer is softer and less acid resistant than enamel. Sensitivity is caused by small tubes in the dentin that connect directly with the nerve of the tooth. Bacteria and acid continue to affect our teeth as tooth decay progresses, passing close to the inner tooth structure (pulp), which includes nerves and blood vessels. The bacterium causes the pulp to swell and become irritating. Discomfort might even spread to the bone beyond the tooth root. Due to these problems the shape and size of teeth can changed. Our tooth requires a crown for support and protection from temperature and further damage. Dental crowns or caps are used to bring the original shape of our teeth after they get changes. It restores strength and appearance. Crowns will protect your loose tooth from breaking and restoring it, covering & supporting the filled tooth, helping in avoiding coloration. Basically, it is made up of metals, porcelain, resin and ceramic. Currently available teeth crowns are gold crown, which is the strongest crown than others and last for 20 to 40 years. Although it is biocompatible, non-toxic, anti-corrosion, and versatile, it has certain adverse effects such as swelling, lip and mouth discomfort, gum irritation, oral lichenoid response, and redness, and moreover it is expensive can't afford by everyone. Porcelain crowns are the most popular crown in the market because; they match the color of the tooth. Commonly it is made up of ceramic known as Feldspathic porcelain. For front tooth repair, porcelain crowns are the finest option. Crowns made of porcelain are not as sturdy as crowns made of gold or metal. These crowns are the most expensive, delicate, and cause more hot and cold sensitivity since the original teeth are anchored deeper into the gums. Zirconium crown is a form of ceramic material, to be more precise, a zirconium oxide which is more durable than porcelain and some metal alloys. The cost of a single zirconia crown ranges from 10,000 to 25,000 INR. Zirconia crowns come with lifespan of 10 years. Titanium crown is biocompatible but still it can cause inflammation and last up to 7 years. Despite the fact that these crowns are biocompatible, non-toxic, and anti-corrosive, they can cause swelling, gum irritation, inflammation, and bacterial infection if the filling is washed away. To overcome drawbacks such as high cost, short lifespan, and inflammation, as well as to reduce production time, we developed a cost-effective and time-consuming customized tooth cap/toot filling using biomaterials (such as Polyvinylpyrrolidone, Beta tricalcium phosphate, and pectin) and advanced 3D printing technology. The chosen biomaterials have regenerative qualities, so they act as a protective layer while also regenerating cells and spontaneously filling in damaged areas. Beta tricalcium phosphate has excellent bioactive and osteoconductive properties that results in rapid bone formation in a host body and strong biological fixation to bony tissues, calcium phosphate materials possess low mechanical strength, which is an obstacle to its applications in load bearing areas. Pectin Nanocomposite can act as a better filler material in the field of dentistry. This project aims that, how 3D printing can be used in dental laboratories for making tooth cap to maximum extent, it attempts to present a rational evaluation of today's restoration; the project discusses future perspective and examines the ongoing viability of traditional dental laboratory services and manufacturing processes. It shows which expertise is needed for the digital additive manufacturing for dental restoration and case report of prosthetic treatment built upon 3D technologies for manufacturing of dental restoration. 3D printing is the innovative method of acquiring the exact same image. CAD software is used to design and simulate the tooth cap in viable environment such that there is no miscible after the implementation.

II.MATERIALS AND METHODS

A. CHEMICAL USED:

Polyvinylpyrrolidone, Beta tricalcium phosphate, pectin, was purchased from Sigma Aldrich. PETG, PCT-G (was used to print a prototype model of tooth cap) .

B. DESIGN OF TOOTH CAP:

To make a tooth cap, first we have to construct a design of tooth cap. It is very difficult to make a design of tooth cap in 3d because the dimensions and structure of the tooth should be aligned properly without any errors. Here, we use RHINO software for modeling of tooth cap. By using this software, we constructed the design of tooth cap with definite dimensions. The produced design was simulated to determine whether the design's basic strength is ideal or not. Rhino can create, analyze, render, edit, translate NURBS curves, Sub -D and polygon mesh. We can create any type of shape and size by using the tools in it. Rhino software is a computer aided design application which is used to do a prototyping on any structure or design. This software is used in dental laboratories. This allows creating aesthetic and durable prostheses for patients. It will increase the simplicity of design and making restorations. It enables the dentist to create a full design in less time. This system will use a camera to take a digital impression by constructing a 3D image which is imported into program and results in computer cast in which design is restored. Then it is simulated using Ansys.

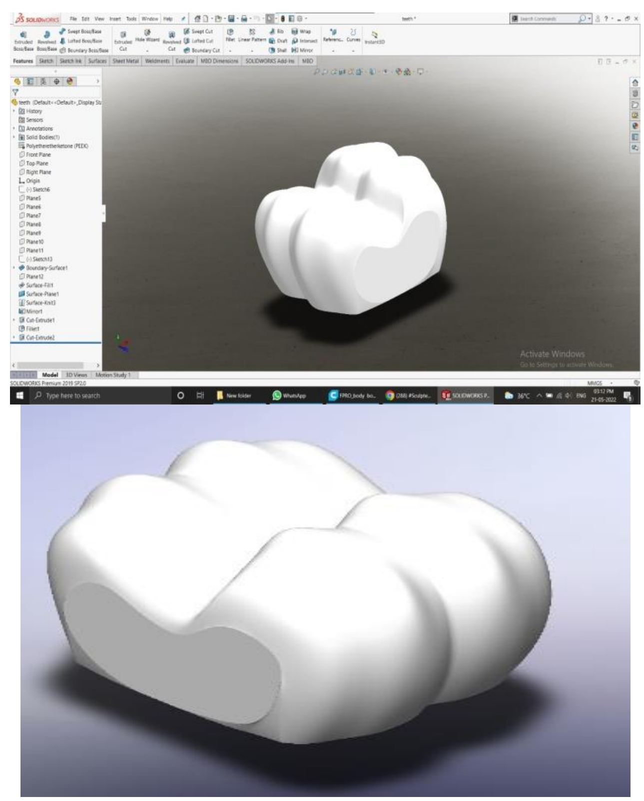

Fig 1. Designing of tooth cap model in Rhino software

ANSYS is a finite-element modelling software that may be used to numerically address a wide range of mechanical problems, including static/dynamic, structural analysis, heat transport, and fluid problems, as well as acoustic and electromagnetic issues. The ANSYS CAE (Computer-Aided Engineering) tool was used to simulate the behavior of designed teeth under structural loading conditions. To simulate, first insert the tooth cap model into the Ansys software, and then we give a external force of 0-14 N. The stress, strain, and displacement of the suggested tooth cap model were investigated and the following results were obtained.

C. PROCEDURE FOR PRINTING A PROTOTYPE MODEL:

Fused Deposition Modelling (FDM), an additive manufacturing technique, was employed to print the prototype model. We printed two prototype models using various materials: PETG (Polyethylene Terephthalate Glycol, black in color) and PCTG (Poly Cyclohexylenedimethylene Terephthalate glycol-modified, white in color). PCT-G polymer is very well suited to applications that need low extractable, excellent clarity, and strong gamma stability. High impact characteristics are also a feature of the material. To distinguish between the coated and uncoated tooth caps, a PETG prototype tooth cap model was coated and filled with slurry. Selective Laser Sintering is an additive 3D printer technology, we will utilize to make the realistic tooth crown in the future. It employs a laser to turn a powder or gel sample into solid matter, and the key benefit is that this is a low-cost mass production approach that does not require the usage of support structures. This is the best option for a functioning prototype and end-use manufacturing. The SLS process begins with the application of a thin slurry coating to the platform's surface (in the build chamber). The slurry is then heated to a temperature below the source ingredients' melting point. The laser examines the 3d model's characteristics before heating the powder to the melting point, fusing the raw material particles, and forming a solid component. During printing, the unfused slurry functions as a support framework. The platform constructs a structure on its own, layer by layer, until it is finished. With the help of the fans that surround the platform, any slurry powder that is not fused to the component is evacuated, and the slurry is stored and reused for another part. Inside the printer, the created tooth cap is allowed to cool. Remove the final components from the build chamber, separate them, and rinse away any leftover powder.

D. MULTIPURPOSE TOOTH CAP SLURRY PREPERATION:

The Slurry for tooth cap was prepared using wet chemical method.

50 ml of distilled water was heated for 5 min using magnetic stirrer at 600 RPM. Every 15 minutes, 0.5g of Polyvinylpyrrolidone was added to the double distilled water and magnetically agitated at 900–1000 RPM. After 20 minutes, 3 g of Beta tricalcium phosphate was added and magnetically stirred for another 20 minutes at 900–1000 RPM. Finally, 3g of pectin were added, and the mixture was magnetically agitated for 40 minutes. We saw that pectin is dissolved with the PVP and β-TCP after 40 minutes.

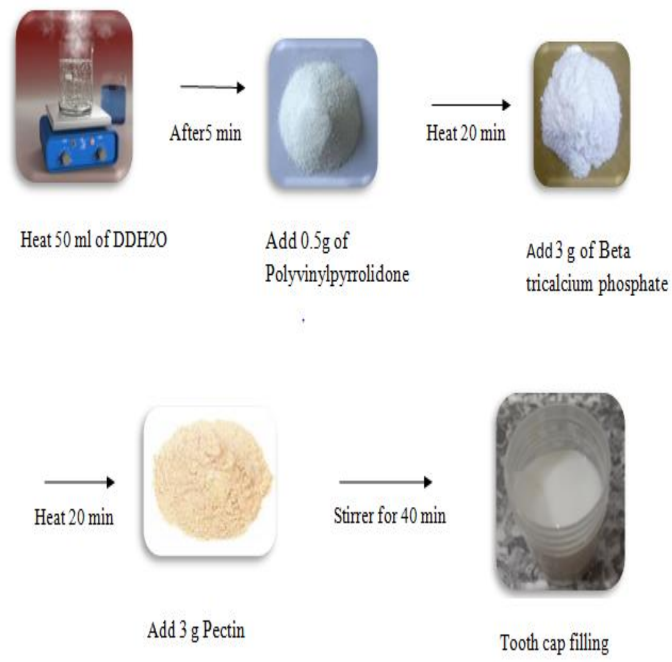

Fig 2. Schematic diagram for slurry preparation

The preparation of multifunctional tooth slurry is depicted in the diagram above. This slurry has been used as a tooth filling and it can also use as a tooth cap material.

E. FUNCTIONAL CHARACTERISTIZATION OF TOOTH FILLING:

FTIR (Fourier Transform Infrared) Spectrum is used to confirm the product materials. The sample for tooth cap was analyzed by passing IR radiation via the sample. When infrared radiation travels through a sample, part of it is absorbed by the sample and the rest goes through is transmitted. The resultant signal at the detector is a spectrum that represents the samples molecular. By analyzing FTIR spectrum against the functional group of materials the presence of chemical components was confirmed.

F. IN-VITRO ANTIMICROBIAL TESTING:

To determine if the dental crowns are effective against germs, antimicrobial susceptibility tests were done. E. coli, Streptococcus, and Pseudomonas bacteria, as well as Candida albicans (fungi), were tested for antibiotic resistance. Antimicrobial test was done by well diffusion method. The whole agar plate surface was inoculated by distributing a volume of microbial inoculum across it. Then 100µl of tooth cap sample was added in to a well created on agar medium then the plate was incubated overnight at 37ºc, after that presence or absence of a zone of inhibition surrounding the disc was measured and resulted below.

III.RESULT AND DISCUSSION

A. SIMULATION OF DESIGNED TOOTH CAP:

B. EQUIVALENT STRESS:

Stress is a physical tension, when blood pressure near the tooth rises, the risk of tooth decay also increases, so how much stress our tooth cap can withstand is simulated before making a prototype model, Fig 3 Shows the deformation of the tooth when a compression force of 14 N is applied. As observed, PETG material tooth designed with maximum deformation of 4.9mm. This 3D tooth prototype with specific diameters has been acquired with the aid of using different scale elements and thickening factors.

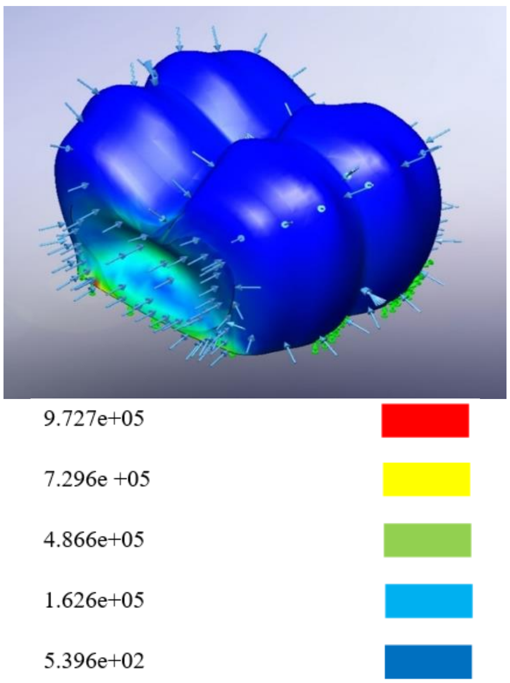

Fig 3. Deformation of tooth

C. EQUIVALENT STRAIN:

Excessive pressure on teeth can cause strain. Our prototype model is simulated to know how much strain it can withstand. Fig 4 shows the deformation of tooth cap model when equivalent strain is applied.

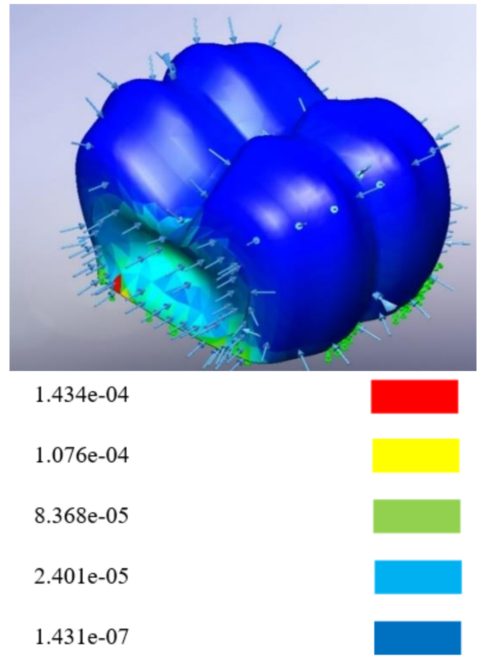

Fig 4. Deformation of tooth when tooth is strained

D. DISPLACEMENT:

Our prototype model's displacement refers to the amount of space it can extend. Deformation is not the same as displacement. Deformation refers to how an object bends, twists, and stretches, whereas displacement refers to how an object moves but not how it stretches or deforms.

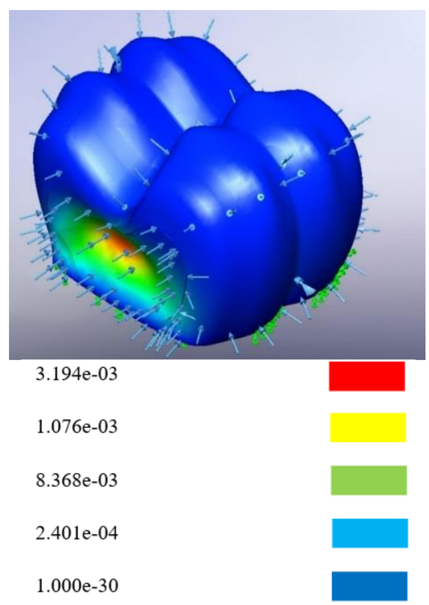

Fig 5. Displacement of designed tooth

As indicated by the research studies, the surface pressure impacts the cell proliferation than the liquid pressure, however the inlet strain influences the mass flow of the nutrient fluid in a tooth without any delay. The highest stress values were shown in the crown in tooth region. Calculated stress values were higher with eccentric occlusal forces in all tooth tissues. The calculated stress, strain and displacement on the tooth cap under functional load measured up to 14 (N) [Figure 3,4,5], while the stresses in the same area under eccentric load are significantly higher and were over 40 (N) [Figure 5] suggested by Selma Jakupović et al (2019).

E. TOOTH CAP PROTOTYPE MODEL:

The prototype model for the intended tooth cap is created using FDS (Fused Deposition Modeling). The upper view of the printed tooth cap model is shown in Figure 8.

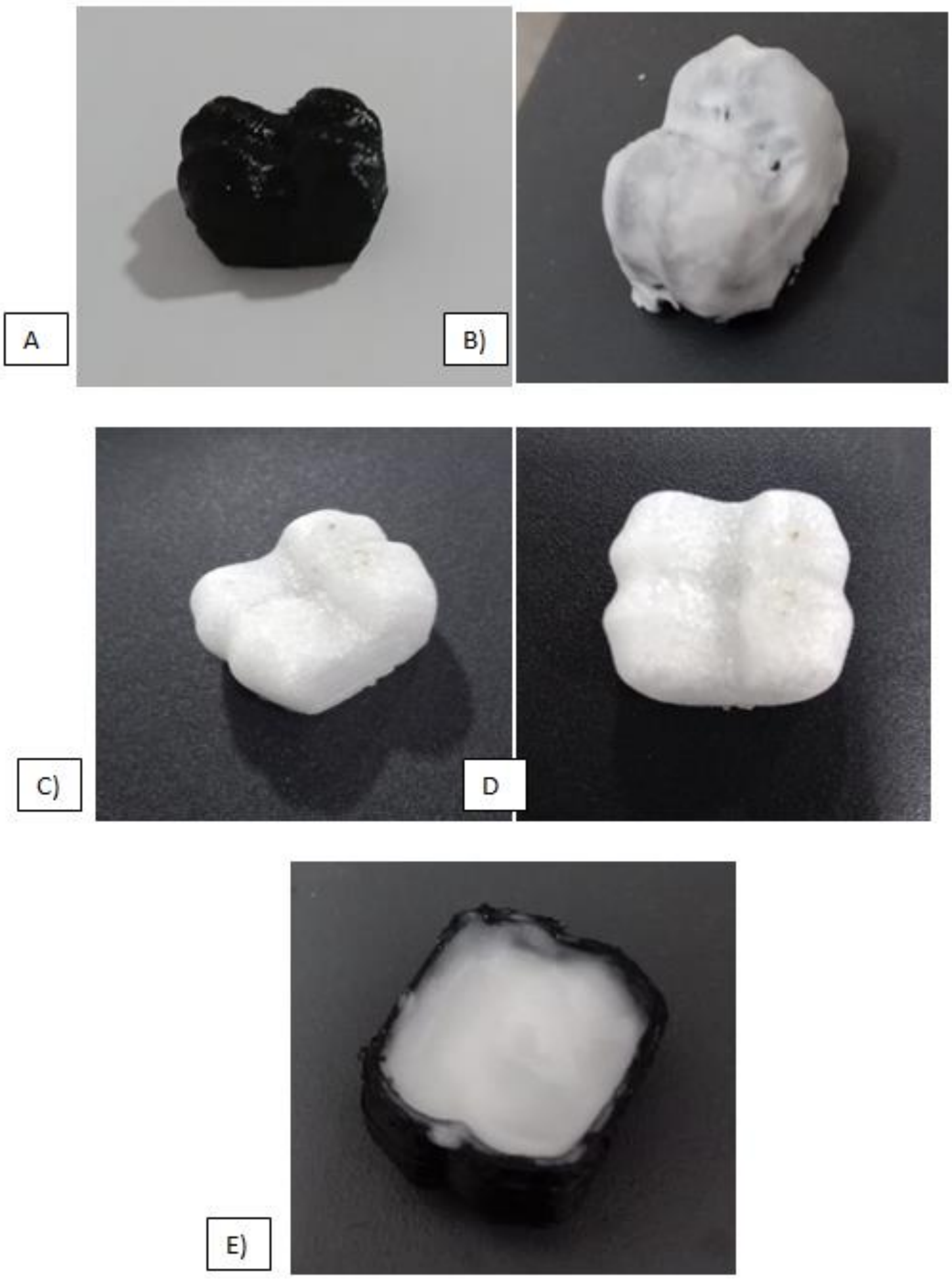

Fig6. A) 3D printed tooth cap model using PETG, B) coated(A), C) and D) 3D printed tooth cap model using PCTG, E) filled tooth cap.

F. STANDARDIZATION RATIO OF BONE FILLING:

Table 1. Trial for Sample Preparation And Its Ratio

S.NO	H2O	Beta-TCP	Pectin	PVP	Chitin
A1.	50ml	3g	3g	0.5g	3g
A2.	50ml	3g	1.5g	0.1g	-
A3.	50ml	3g	2g	0.25g	-
A4.	50ml	3g	2.5g	0.4g	-
A5.	50ml	3g	3g	0.5g	-

Bone filling is an artificial bio-degradable substance, implanted in our body to repair and able to regenerate tissue growth in an injured or infected part of tooth. Numerous materials are available such as chitin, pectin, alginate, gelatin, poly lactic acid, and so on. As shown in Table 1, five samples (A1, A2, A3, A4, A5) with different combinations of Beta-tricalcium phosphate, pectin and PVP were prepared to standardize the bone filling slurry using wet chemical method. Among the samples used to prepare the bone filling, sample A4 & A5 exhibited a perfect slurry combination than the other combinations. Hence A4 & A5 sample ratios was considered as an ideal combination for preparation of bone filling. Therefore, A5 sample was subjected to further characterization studies. Beta-tricalcium phosphate which mimics body calcium phosphate component and enrich our cell proliferation. Pectin gives a good potential strength to support the re-growth of the tissue. Slurry consistency gives its unique support to the cell proliferation around the cells. The standardized ratio of bone filling preparation is given in table 1.

G. FUNCTIONAL CHARACTERISTICS OF TOOTH FILLING:

FTIR spectral analysis of tooth filling slurry was represented in Fig Beta-tricalcium phosphate exhibits the characteristic peak bands of phosphate group (PO4), pectin, PVP and water. The peaks at 1000cm-1 and 550cm-1 are assigned to vibrations of phosphate group, PO4 (pang et al., 2016). The phosphates have double bond group PO4 form intensive IR absorption bands at 800cm-1 to 400cm-1 and 1000cm-1.

Table 2. FTIR Spectroscopy of Tooth Filling

Wavelength	Chemical Bond	Functional Group
3400-3200	N–H stretch, O–H stretch, free hydroxyl	1°, 2° amines, amides, alcohols, phenols
1800-1500	C=O stretch	carboxylic acids
1500-1000	C–C stretch (in–ring), C–O stretch	Aromatics, alcohols, carboxylic acids, esters, ethers
800-400	C–Cl stretch, –C ≡C–H: C–H bend	alkyl halides, alkynes
3400-3200	N–H stretch, O–H stretch, free hydroxyl	1°, 2° amines, amides, alcohols, phenols
1800-1500	C=O stretch	carboxylic acids

The FTIR absorption band of beta tri-calcium phosphate peaked at 1050cm-1 and it contain calcium, phosphorous and oxygen groups. The peak corresponding to the bending mode of O-P-O bonds falls on 550cm-1. The absorption bands of amide I and amide II related to pectin group observed in the spectra of the slurry composite. Ghosh, R, et, al, 2016 suggested that characteristic band for stretching mode of PO4 3− group sample at 493 cm−1 and the bending vibrational peaks of PO4 3− in β-TCP respectively. The peak at 3432 cm−1 which were attributed to adsorbed water and 3572 cm−1 sharp peak stretching vibrations of lattice OH– ions indicating the presence of little TCP impurity at 800 °C.

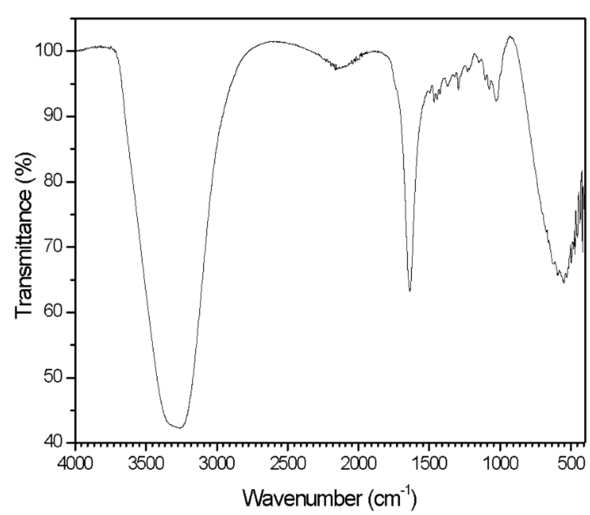

Fig 7. FTIR analysis of prepared sample

N. Rajeswari, et, al (2011) reported that PVP, the bands at about 3480 cm^{-1} are assigned to OH stretching. The band at about 1078 cm^{-1} corresponds to C\O stretching of acetyl groups present on the PVA backbone. The vibrational bands at about 1694 cm^{-1} correspond to C_C stretching of PVP. The bands at 2179 cm^{-1}, 1731 cm^{-1}, 962 cm^{-1} and 864 cm^{-1} in Fig 7 have been assigned to C\N stretching, C_O stretching, C\C bonding and CH_2 bending vibrations of pure PVP respectively.Giada et al., 2013, observed that the IR spectral study of pectin band peaked at 1800cm-1 C=O stretch corresponding to amide I group. In the present study the absorption band of the amide I and amide II related to pectin can observed in the FTIR spectra of tooth filling slurry. The bands are generally larger due to the macro and micro molecular structure of the compound containing numerous intermolecular bindings.

H. IN-VITRO ANTI - MICROBIAL TESTING:

The antimicrobial activity of multipurpose tooth filling (contain pectin, beta tricalcium phosphate and polyvinyl pyrrolidone) was investigated against E. coli, Streptococcus, Pseudomonas, and Candia Albicans through well diffusion method and the overall inhibition was 49 % which is correlated with (UlinAntobelli Basilio Cortes et al., 2021) he reported that S. aureus showed to be the most resistant microorganism.

Fig 8. a) Candida Albicans, b) Pseudomonas, c) E. Coli, d) Streptococcus. These microbes are used to perform the antimicrobial test

The tooth filling slurry killed the microorganism by creating holes in bacteria's cytoplasmic membrane, allowing cytoplasmic material to flow out, resulting in cell death (Carson et al., 2002; Guerra-Rosas et al., 2017). When pectin came into contact with bacterial cells, its carboxylic group (-COOH) deprotonated. The -COOH ion was transformed to the carboxylate ion (COO) and the H^+ ions. The bacterial cells' pH was altered by H^+ ions. The bacterial cell wall was broken, and carboxylate ions reduced cellular activity by attaching to positive bacterial cell species (Kundukad et al., 2017). When the concentration reached 3 mg mL1, both pectin and Integro Pectin inhibited S. aureus growth, with a drop in the number of viable cells ranging from 1 to 2 log units (Dr. Alessandro Presentato et al., 2020).

IV. CONCLUSION

The customized tooth cap was developed using 3d printing with the compositions of biomaterials like beta tricalcium phosphate, Polyvinylpyrrolidone and pectin. By the combination of the above materials, we formed multipurpose tooth filling/tooth cap slurry and it was tested with FTIR and in-vitro anti-bacterial study. The results show that the slurry contains all the required composites in it. Which makes the tooth cap strong, durable, low cost and the most sold tooth cap. These are made by bio-ceramics similar to our natural teeth composites. The main disadvantage of using porcelain materials are they get coloration fast and fragile and sensitivity. But by using the Polyvinylpyrrolidone teeth won`t get colored easily and stops from getting irritation in gums. TCP makes the hard structure and strong tooth cap than the porcelain tooth cap. Pectin is used to stand by as the protective layer for teeth. So, by using these natural biomaterials we can make the tooth cap in best quality. 3D printing can make the production of tooth cap faster than present technologies. Patients no need to wait for longer period time and making to visits with dentists are not necessary. We can design them after taking the patients dimensions and printing it will take few hours, we can make bulk amount of production too. Thus, tooth cap and tooth filling prepared by 3D technology using beta tri-calcium phosphate, pectin and PVP unfolds a new arena in dental care.

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