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Fabrication of Customized Bioactive Scaffolds for the Repair of Bone Defects Using 3D Printing

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ABSTRACT

3D-printing is a hot topic of today's technological discussion. A large number of research papers have been published every year on additive manufacturing and its application in medical cases. A significant number of papers from that are studied and various applications of 3d-printing in the field of medical analyzed for delivering the best and reliable method for the development of scaffolds and biomedical implants. This study will illustrate the advantages of 3D-printing as compared to conventional manufacturing methods. Numerous applications of additive manufacturing are represented in the different field of today's world. The paper aims to show the 3D-Printing technology as being utilized in medical and its advantages alongside present days and future applications.

Conclusion: Paper presents the literature review of medical application of 3-D Printing and its future scope. 3-D medical models are prepared with reverse engineering to design and manufacturing of customized implants and bones. It modified and customized as pre patient requirements. It may be different for every patient and can be modified. It provides the extensive benefits to humanity in short time as compared to other manufacturing processes.

Keywords: 3D printing, 3D scanning, Additive Manufacturing (AM), Implant, Scaffold, Biomedical material, Medical Applications and Rapid Prototyping (RP)

1. Introduction

3D-printing is a process for making a 3D object of desired shape and size from the 3D model. This 3D model is prepared in CAD software or generated from scan data of a specific patient. It is an additive process in which several layers are added under computer control. The additive manufacturing process is totally opposite from the subtractive process, where the material is removed from a block layer by layer such as in the case or drilling, milling and facing. 3D-printing starts in 1981. Dr. Hideo Kodama of Nagoya Municipal Industrial Research Institute patent first application for rapid prototyping machine. First ever patent filed in this field by Dr. Kodama in which a laser beam was used to resin solidifying is depicted. In1986 Charles hull of 3D System Corporation developed the first working 3D printer [1]. Charles hull

was a pioneer of the solid imaging process. Stereolithography (STL) developed by Charles hull is still widely used in 3d printing. After the first printer was evolved the machine becomes more and widely used in the field of engineering and research. The machine price is lowered and becomes more affordable.
In the last few years, rapid prototyping has a wide range of applications in the field of research, aerospace, medical industry, production engineering, and architecture and computer industries.

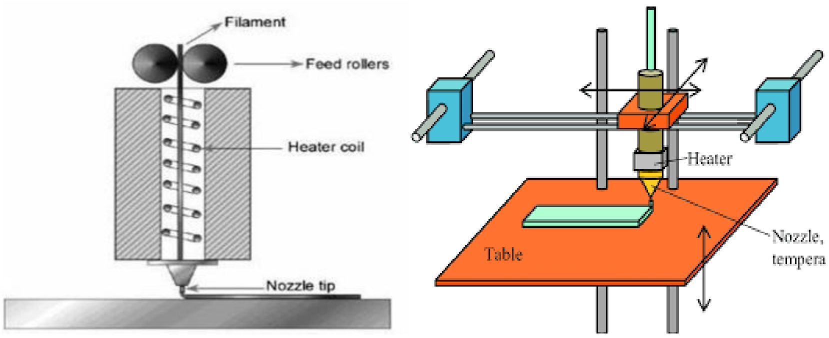

Fig 1: 3D Printing Process

3D- Printing technology in the field of medicine plays a vital role, by offering promising quality and close to the original one for bone regeneration rehabilitation and reconstruction [2,3] and extending treatment in the
field of Surgery [4]. Since then, many assorted procedures and manufacturing techniques have developed, in viewing the same objectives to produce 3D structures that emulates the internal and external geometrical shapes of authentic ones [5] and deliver essential structure for migration and call attachment, thereby inciting tissue regeneration. On other hand such a customized and modified framework function as filling and loading material that renovate the impaired sites. 3D tailored made scaffolds developed with signaling biomolecules and stem calls, have lately been effectively implanted into targeted defects [6,7].
There is a group of technology for describing 3D-Printing: Rapid prototyping, solid freeform fabrication and additive manufacturing. 3D technologies involve in the development of well-defined 3d shape from designed computer aided design model by layer-by-layer addition [8].
The medical imaging technology, especially magnetic resonance imaging (MRI) and computer tomography (CT) provided the information for model designing. The captured raw imaging data are refined and retraced as a 3D-model, which is then transferred to 3D printer for the execution.
Computer aided manufacturing methods are used to design and develop 3D objects, based upon anatomical information of tissue, to reconstructed. After that scaffolds 3d-Printing started by adding a layer of biological materials, with tailored shape and inner porosity, enhanced with biomolecules and seeding cells in multiple combinations [9,10].

2. Manufacturing in medical field

There are significant manufacturing developments in the field of medical made by this technology.

a. Designing and development of bio implants.
b. Reducing operation time.
c. Developing lightweight and desired porosity implants.
d. Producing improved quality implants.

e. Achieving excellent surface quality.
f. Exact size, shape and matching of tailor-made parts.
g. It providing pre surgical planning to surgeons and it also helps the students for better understanding.
h. Provides substitution for the replacement of defected bones.

Hutmacher stated that there is a primary requirement of robust bone and reconstruction of osteochondral methods which takes into account certain factor like biochemical, morphological and anatomical [11]. Defected area bone can be substituted with new one. The substituted required bone can be manufactured with the help of 3D-printing. These bones replace the defected area. Hieu et al. generated the design data during the processing of medical images (magnetic resonance imaging (MRI) and computer tomography (CT)) and represented the design method of cranioplasty implant employing medical 3D-printing technology. To construct the 3D model reverse engineering methods is used. All this is based on different type of data extracted from bone slice contours ((IGES) and (SSL)) and Stereo Lithography files (STL) [12]. This method is more helpful and advantageous for the design and manufacturing of medical implants. He et al. represented designing and fabrication process composed of porous titanium alloy and bio ceramic relaying on 3D-Printing technology for a Hemi- Knee joint. With the help of reverse engineering and CT Image the rebuilding of femur bone was made and precisely judged. The deviation of 0.206 mm of 3D rebuilt model from original anatomy [13]. The result of the experiment shows that substitutes bone has good mechanical strength and matches well. Willis et al. stated that additive manufacturing is necessary for the generation of 3D objects from CAD models. 3D- Scanner is used to capture and extract the model data. This digital model data was processed, modified and the prototype is developed with the help of3D-Printing [14]. High accuracy is attained for deep concavities and complex shape of developed object.

Hutchinson found the demand of tailor-made fabricated bone and joint with the help of additive manufacturing has increased due to spinal deformation, spinal code injuries, osteoporosis traumatic musculoskeletal injuries and arthritis. The use of Joint manufactured with 3D-Printing has increased in the field of medical [15]. explained 3D model developed form CT data with 3D-Prinitng has various clinical applications like surgical communication and planning. Patient are communicated well with 3D models and the model also used in prosthesis and surgical planning [16].

Van Noort defined 3D-Printing makes surgery cost effective, faster and accurate than manual process. The cost of model manufactured with 3D-Printing is low as compared to model developed by other method. The accuracy of 3D printed model is also high [17]. Evila et al. research work focused on designing and manufacturing of tailored tracheal stent by 3D-printing. The overall manufacturing efficiency of tailored tracheal stent is increased with this automatic and novel system. The surface quality achieved during this research work is excellent and manufacturing cost also reduced [18].

Ibrahiem et al stated 3D-Printing developed all human parts. Many plastic surgeons give preference to fat structural graft. With this method both aesthetic and reconstructive surgery is archived easily. This technique is a worthwhile for soft tissue augmentation [19]. Mishra stated 3D-Printing technology is used to develop custom sizes valve to the patient. Biological material can be used for the development of valve by 3-D printing, it could grow with patient. Soft and elastic material was used to create 3-D shape by biomedical engineers which truly matched heart epicardium [20].

3. Finding the bone defects using the x-ray report

Analyzing an X-ray report for bone defects involves a thorough examination of the bone structure, looking for irregularities or anomalies that may indicate underlying issues. One of the primary indicators is the presence of fractures, which appear as discontinuities or breaks in the bone. Fractures can vary in severity, from hairline cracks to complete breaks. Additionally, areas of decreased bone density, known as osteopenia or osteoporosis, may suggest weakening of the bone due to various factors such as aging or hormonal changes.

Other abnormalities to look for include bone lesions, which are areas of abnormal tissue growth within the bone. These can be benign or malignant and may require further evaluation through additional imaging or biopsy. Joint spaces should also be examined for signs of arthritis or degenerative changes, such as narrowing or irregularities in the joint surfaces.

Soft tissue swelling or calcifications adjacent to the bone can indicate inflammation or the presence of soft tissue tumors. Finally, assessing the alignment of bones and joints can help identify dislocations or subluxations, where the normal alignment of the bones is disrupted. Overall, a comprehensive evaluation of the X-ray report by a trained radiologist or medical professional is essential for accurate diagnosis and treatment planning


Fig2:CT Scan

4. Designing the 3D model of the bone using the CAD software and converting that file in to STL format:

In CAD software, designing a 3D model of a bone requires a systematic approach. Begin by referencing anatomical diagrams or 3D scans to understand the bone's structure accurately. Create a base sketch, typically using the software's sketching tools, to outline the bone's general shape. Ensure precise dimensions, considering both length and width proportions. Next extrude the sketch to give it depth, essentially turning the 2D outline into a 3D object. This step establishes the basic form of the bone. Adjust the extrusion depth to match the bone's thickness, keeping anatomical accuracy in mind.

Now, refine the model by adding intricate details such as ridges, joints, and surface textures. Utilize features like extrusions, fillets, and patterns to mimic the bone's natural features realistically. Pay close attention to anatomical landmarks and features that affect the bone's functionality. Continuously assess the model from various perspectives to ensure accuracy and symmetry. Fine-tune dimensions and details as needed to enhance realism and functionality. This iterative process may involve revisiting earlier steps to make necessary adjustments. Finally perform a thorough inspection of the completed model to verify its accuracy and suitability for its intended purpose, whether it's for medical research, educational purposes, or artistic rendering

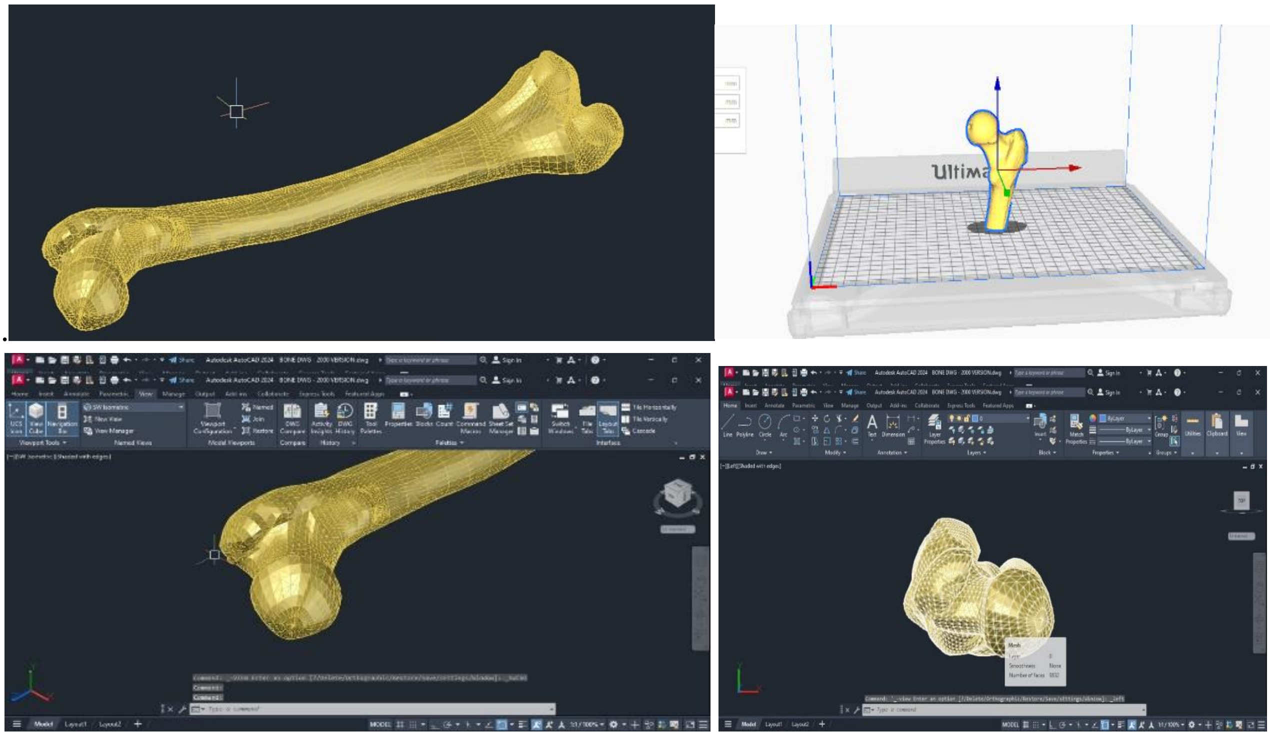

Fig 3: CAD Design models

5. Selecting the PLA filament for printing the bone using 3D printing:

When selecting PLA filament for printing bones using 3D printing, consider its biodegradability, low toxicity, and ease of use. PLA (Polylactic Acid) is derived from renewable resources like corn starch or sugarcane, making it environmentally friendly. Its low toxicity makes it safe for printing objects that may come in contact with skin.

PLA is also easy to work with, requiring minimal adjustments to print settings and offering good adhesion to the print bed. Its low shrinkage rate reduces the risk of warping during printing, ensuring better accuracy and dimensional stability, important for intricate bone structures.

Additionally, PLA comes in a variety of colors, allowing you to customize the appearance of your printed bones as needed. However, it's worth noting that PLA may not be suitable for applications requiring high temperature resistance or extreme durability.

Overall, PLA filament is an excellent choice for printing bones due to its eco-friendliness, safety, ease of use, and reasonable cost, making it suitable for various educational, research, or artistic projects.

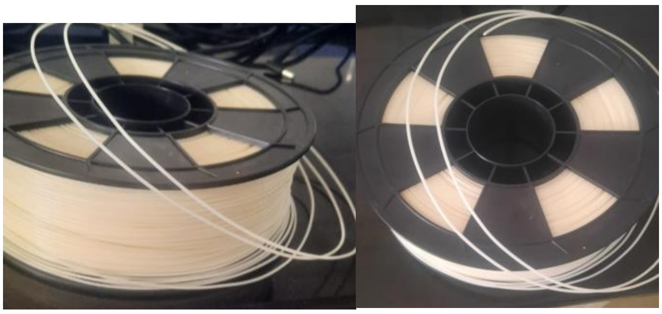

Fig 4: 3D Printing Filament

6. Testing the strength of the PLA material:

- **Tensile test**
- Prepare standardized PLA specimens with precise dimensions.
- Securely attach one end of the specimen to the fixed grip of the tensile testing machine and the other end to the moving grip.
- Apply a controlled force to the specimen, gradually increasing until it fractures.
- Record the maximum force applied (in Newtons) and the corresponding elongation.
- Calculate the tensile strength by dividing the maximum force by the cross-sectional area of the specimen.
- Repeat the test with multiple specimens to ensure accuracy.

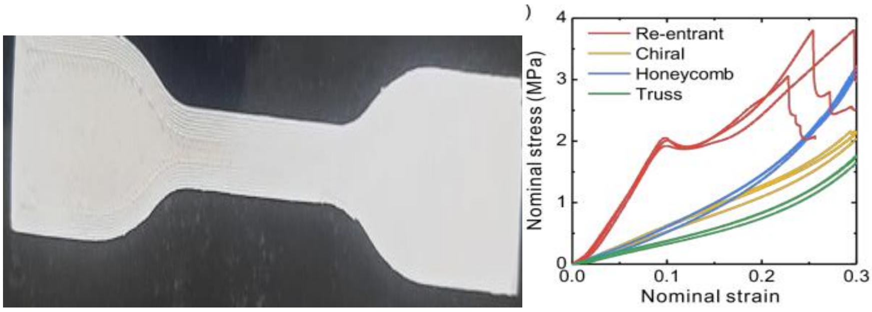

Fig 5: Tensile Specimen and Result

- **Impact strength**

Prepare PLA specimens in the desired shape for impact testing, typically rectangular or notched specimens.

- Use a pendulum impact tester or Charpy impact tester to conduct the test.
- Secure the specimen in place, ensuring it is properly aligned with the striking edge of the pendulum.
- Release the pendulum, allowing it to strike the specimen with a controlled force.
- Measure the energy absorbed by the specimen during impact, which is indicated by the pendulum's swing.
- Record the results and calculate the impact strength of the PLA material.
- Repeat the test with multiple specimens to ensure consistency.

By conducting both tensile and impact strength tests, you can assess the mechanical properties of PLA material comprehensively, helping determine its suitability for various applications, including 3D printing bones.

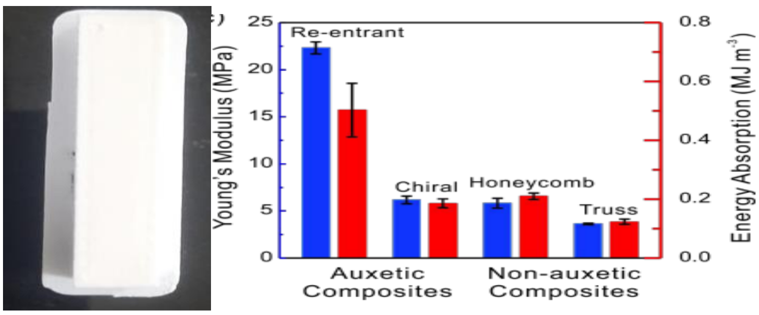

Fig 6: Impact Specimen and Result

7. Infill Density to 3D printing:

In 3D printing, infill density refers to the amount of material used to fill the interior of a printed object. It's expressed as a percentage, representing the density of the infill compared to solid material. Higher infill densities result in stronger and more durable prints but also require more material and time to print. Lower infill densities save material and time but may result in weaker prints with less structural integrity. Common infill densities range from 0% (hollow) to 100% (solid). However, most prints use infill densities between 5% and 50%, depending on factors like the intended use of the object, desired strength, and printing speed.

For objects that require support or internal structure, higher infill densities are typically used. For decorative or lightweight objects, lower infill densities may suffice. Experimentation with different infill densities allows users to find the balance between strength, material usage, and print time based on the specific requirements of their project

Specimen having 75% infill density shows the good results in mechanical testing

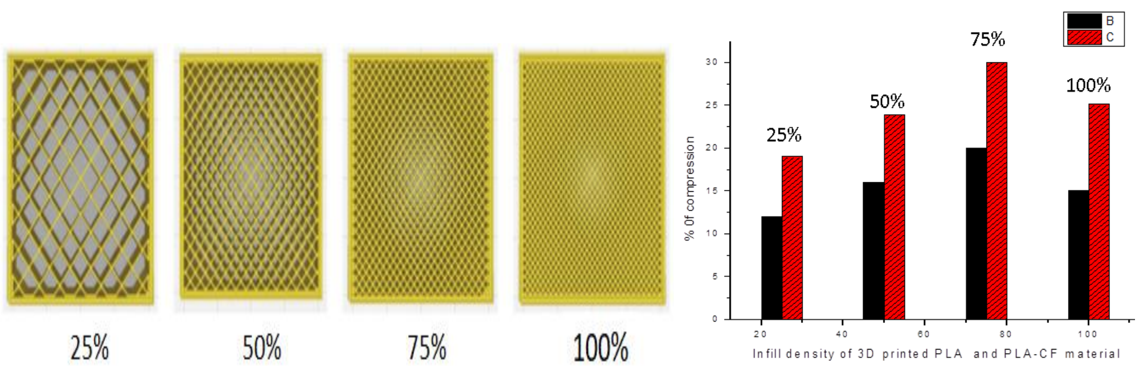

Fig 7: Infill Density of Filament

8. Printing of bone using 3d printing:

To start printing a bone using 3D printing, follow these steps:

- Prepare the Digital Model: Obtain a digital 3D model of the bone you wish to print. This can be created using 3D modeling software, generated from medical imaging data (such as CT scans), or downloaded from online repositories.
- Import the Model: Load the digital model into slicing software, which converts the 3D model into printable layers. Adjust settings such as layer height, infill density, and support structures as needed.
- Select Printing Parameters: Choose the appropriate printing parameters based on your 3D printer and the desired quality of the print. This includes selecting the printing material, nozzle temperature, print speed, and layer adhesion settings.
- Prepare the Printer: Ensure your 3D printer is calibrated and properly maintained. Load the selected printing material (e.g., PLA filament) into the printer's extruder and level the print bed to ensure proper adhesion.
- Start Printing: Initiate the printing process using the sliced file generated by the slicing software. Monitor the print progress periodically to ensure proper adhesion and quality. Depending on the size and complexity of the bone model, printing may take several hours to complete.
- Post-Processing: Once the printing is finished, carefully remove the printed bone from the print bed. Remove any support structures and perform any necessary post-processing, such as sanding or

smoothing rough surfaces.

- Inspect the Print: Thoroughly inspect the printed bone for any defects or imperfections. Ensure that the dimensions and details of the printed bone match the original digital model.
- Utilize the Printed Bone: The printed bone can now be used for various purposes, such as medical education, surgical planning, research, or as a display model.

By following these steps, you can successfully start printing a bone using 3D printing technology, creating accurate and detailed models for a variety of applications.

Fig 8: 3D Printing Machine

Fig 9: Final model

9. Application

a. This technology is assisting in custom made implants for the patient which is less required and differ for every patient.
b. It fulfills the need easily, in less time and at affordable prices.
c. The accuracy of different implants made for a different patient is very good and the surface finish is also very good.
d. The model production with the help of this technology is fast. No tooling and fixtures for this

technology.

e. Researchers successfully print ears. Skin kidney, bones and blood vessels with the help of this technology.
f. Houses are also printed with the help of this technology.
g. The complex shapes of aeronautics and aerospace industries are easily formed with high accuracy. With modern conventional methods manufacturing of these is very difficult and accuracy is also very low.

10. Conclusion

3D- Printing reshapes and revolutionized the world. The manufacturing of custom implants is very easy and cost effective with 3D-Printing. With this high accuracy and surface finish can be achieved. It is very fast and reliable method in the field of medical science. The costs of tailor-made parts are also less as compared to other methods. This technology is also proving beneficial in some critical condition of patient. The manufacturing of scaffolds tissue and bone should be considered as promising with this technology. 3D-Printing provide extensive support in medical application. It is also exploring new market to help humanity.

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