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Robust application of 3-D Printing in Healthcare

Shaik Wasim S A[1], Saifulla[2], Devasis Pradhan[3]

4th Year, BE, Department of Electronics and Communication Engineering,

Acharya Institute of Technology, Bengaluru, Karnataka[1,2]

Assistant Professor, Department of Electronics and Communication Engineering,

Acharya Institute of Technology, Bengaluru, Karnataka[3]

Abstract: 3-D printing has drastic expansion and has been a multidisciplinary research field attracting health professionals throughout the globe. It is a technique of three-Dimensional modelling of an object by hardening the material under the control, basically converting **DICOM** (Digital Imaging and Communication) images into stereo lithographic files. In early stages of its invention it was primarily and extensively used for two purposes one was for craniofacial modelling and the other was for dentistry, but as time passed by, it made a major impact on medical fields like anatomical models, bio printing, medicinal education, tissue engineering, etc. where the scaffold (3-D structure) are formed which are used for formation of new viable tissues for medical purposes. Recent days, 3-D printing technique symbolizes big opportunity to aid medical and pharmaceutical sectors enabling rapid production of medical implants, medicine and changing the way doctors and surgeons plan procedures. The overall aim of this paper is to explore through and provide a survey on all these recent technologies and theoretical concept explaining the development of 3-D printing mainly in the healthcare sector. This paper intends to introduce with a brief explanation as to how and why 3-D printing in healthcare is changing practices, teaching and research.

Keywords: Tissue engineering; Anatomical models; Customized implants prostheses; 3-D vascularised organs.

I. INTRODUCTION

Additive manufacturing which is a synonym for 3D printing may be the eye-catching development in printing since Gutenberg developed the first printing press 600 years ago.[2] A machine that can make copies of almost everything seems like science fiction but in the current scenario, 3D printing is already in use in building construction, jewellery, hearing Aid, organ implants and even Parts for NASA too. Now the technology is becoming available to everyone meaning you can turn your garage into a small 3D printing factory .3D printing is a process of digital fabrication of a 3D objects of any shape and size through additive processes in which successive layers of material are laid down under the computer control.[4]
Nowadays, Rapid prototyping has a wide range of applications in various fields of human activities, especially in medical and healthcare sector it is used to assist our physician in pre-surgical planning materials for some special and Critical cases where a thorough knowledge is needed about the damage of deceased internal organ .3D printing in Healthcare is majorly used for three purposes clinical application, educational purpose and Research application. 3D printing is a very essential aspect to educate young doctors and physicians about a three-dimensional view of a particular internal organ.[1] It gives a realistic and clear view of not only the morphological appearance of an inner organ but also its functionality too.

II. HISTORY

Hideo Kodama of Nayoga Municipal Industrial Research Institute is generally regarded to have printed the first solid object from a digital design. However, the credit for the first 3D printer generally goes to Charles Hull, who in 1984 designed it while working for the company he founded, 3D Systems Corp.[1]

Charles a Hull was a pioneer of the solid imaging process known as Stereolithography and the STL (Stereolithographic) file format which is still the most widely used format used today in 3D printing. He is also regarded to have started commercial rapid prototyping that was concurrent with his development of 3D printing.[2,5,7] He initially used photopolymers heated by ultraviolet light to achieve the melting and solidification effect. Since 1984, when the first 3D printer was designed and realized by Charles W. Hull from 3D Systems Corp., the technology has evolved and these machines have become more and more useful, while their price points lowered, thus becoming more affordable.

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In 1990, the plastic extrusion technology most widely associated with the term "3D printing" was invented by Stratasys by name Fused Deposition Modeling (FDM). After the start of the 21st century, there has been a large growth in the sales of 3D printing machines and their price has been dropped gradually.[3]

By the early 2010s, the terms 3D printing and additive manufacturing evolved senses in which they were alternate umbrella terms for AM technologies, one being used in popular vernacular by consumer - maker communities and the media, and the other used officially by industrial AM end use part producers, AM machine manufacturers, and global technical standards organizations. Both terms reflect the simple fact that the technologies all share the common theme of sequential-layer material addition/joining throughout a 3D work envelope under automated control.

Fig. 2.1 Time Line of 3- D Printing

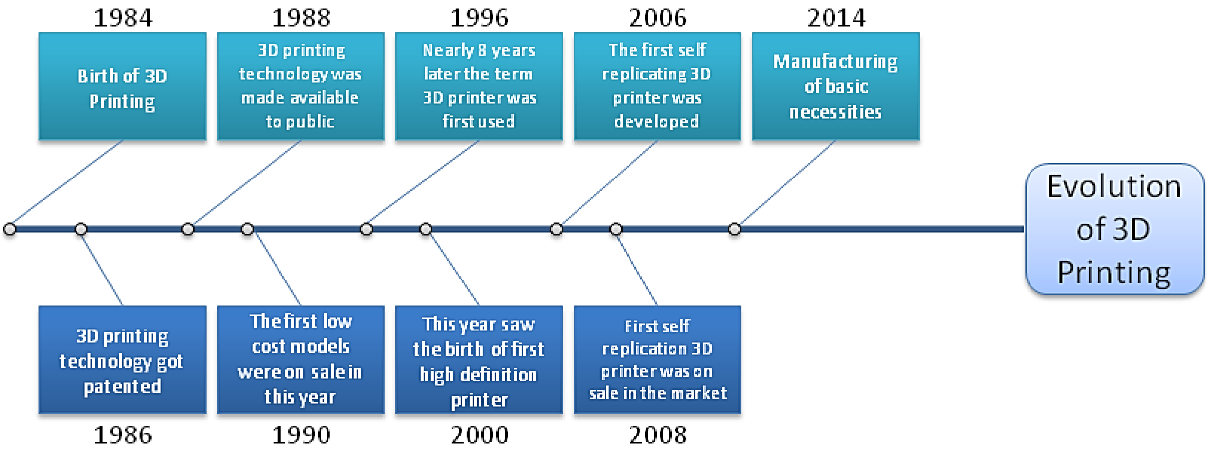

Figure above is a timeline of 3-D printing.[2,4]

III. 3-D PRINTING

Three-Dimensional (3D) printing is a manufacturing method in which objects are made by fusing or depositing materials—such as plastic, metal, ceramics, powders, liquids, or even living cells in layers to produce a 3D object. This process is also referred to as Additive Manufacturing (AM), Rapid Prototyping (RP), or Solid Free-Form Technology (SFF).[2] There are about two dozen 3D printing processes, which use varying printer technologies, speeds, and resolutions, and hundreds of materials. These technologies can build a 3D object in almost any shape imaginable as defined in a stereolithographic file.[3]

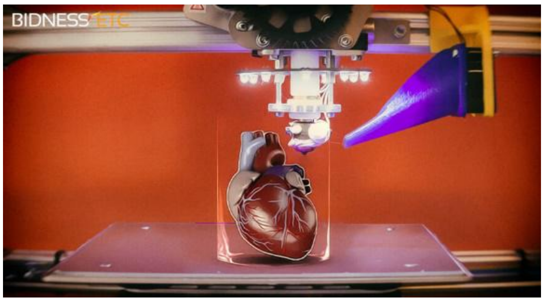

Fig. 3.1 3-D Printed Heart

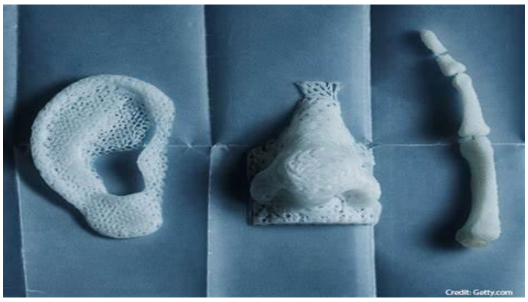

Fig. 3.2 3-D Printed Organ

In a basic setup, the 3D printer first follows the instructions in the stereolithographic file to build the foundation for the object, moving the print head along the x-y plane. The printer then continues to follow the instructions, moving the print head along the z-axis to build the object vertically layer by layer. It is important to note that Two-Dimensional (2D) radiographic images, such as x-rays, Magnetic Resonance Imaging (MRI), or Computerized Tomography (CT) scans, can be converted to digital 3D print files, allowing the creation of complex, customized anatomical and medical structures. [6] This process is repeatable, accurate, and cost-effective for small production runs, allowing the reliable production of customized parts. It also allows fast production and collaboration between physicians and researchers, who can now share a physical object over the internet and recreate it quickly with high precision.[3]

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IV. CLASSIFICATION

a. EXTRUSION

Fused Deposition Modelling (FDM) is perhaps the most affordable form of 3D Printing and is the most popular 3D Printing process FDM is an additive manufacturing technology commonly used for modeling, prototyping, and production applications by forcing through 3D printer filament through a Print Nozzle[6,12] . A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off.

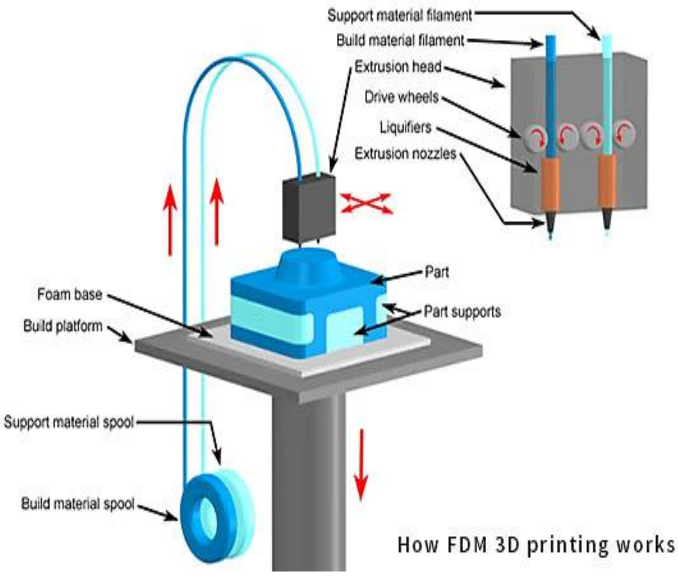

Fig. 4.1 Fused Deposition Modelling

Stepper motors or servo motors are typically employed to move the extrusion head. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a controlled mechanism.[7] The Filament is placed down in layers, one on top of another until the object is complete as shown in figure 4.1. These Filaments are known as thermoplastic, most commonly used 3D Printer Filaments are ABS and PLS. FDM is a trademarked term and a 3D Printing process developed by the Stratasys Corporation.[6,8]

b. SLA – STEREOLITHOGRAPHY (LIGHT POLYMERIZED)

Stereolithography employs a vat of liquid ultraviolet curable photopolymer "resin" and an ultraviolet laser to build parts layers one at a time. Photopolymers are polymers which change their properties when exposed to light. These polymers that can be manipulated using light intensity are said to be curable. [9,12] For each layer, the laser beam traces a cross-section of the part pattern on the surface of the liquid resin. Exposure to the ultraviolet laser light cures and hardens the pattern traced on the resin and joins it to the layer below as shown in figure 4.2.1.

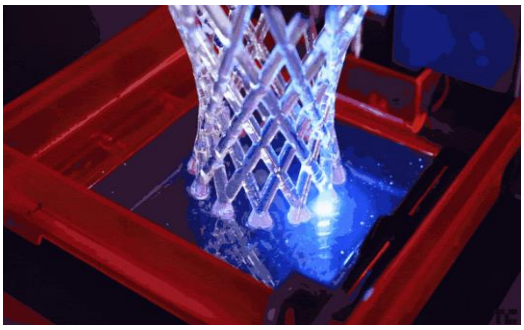

Fig.4.2.1 Light Polymerization

After being built, parts are immersed in a chemical bath to be cleaned of excess resin and are subsequently cured in an ultraviolet oven.[7,9] SLA is one of the fastest forms of 3D Printing and can produce strong parts and objects, but in the past has not been widely adopted among hobbyists and small business due to the high cost of the Printers.[10]

c. SLS-SELECTIVE LASER SINTERING

SLS begins with CAD data to the desired path inside the vanguard build chamber. It uses a high-power laser (for example, a carbon dioxide laser) to fuse small particles of plastic, metal, ceramic, or glass powders into a mass that has a desired three-dimensional shape.[13] Mirror directs the laser beam across the bed of powder. The SLS machine preheats the bulk powder material in the powder bed somewhat below its melting point, to make it easier for the laser to raise the temperature of the selected regions the rest of the way to the melting point as shown in figure 4.3.1.

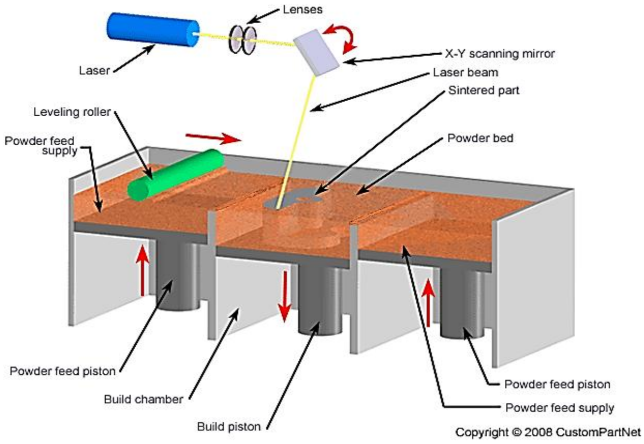

Fig. 4.3.1 Selective Laser Sintering

The CO_2 laser selectively scans the powder bed. A new layer of powder is added, typically0.1mm-0.15mm. This layer is then melted thus building the part layer by layer. During the breakout stage of the process, 50% of loose powder can be recycled. Dura form materials are used which are polyamide based(nylon). These models exhibit highly detailed geometries and customized body fitting geometries.[14,10]

d. ELECTRON BEAM MELTING

Electron Beam Melting, also called as EBM, is a 3D printing process that enables printing of metal parts. Using EBM, it is possible to manufacture parts which were previously impossible to manufacture otherwise. The material used in electron beam melting process is basically a metallic powder in pure alloy form – no additional filler material is used in the mixture.[15,11]

The process begins with a layer of metal powder placed on a temperature-controlled print platform. The chamber is vacuum-sealed to minimize any effect of oxidation on the material. The electron beam printer head travels above the powder layer while internal electromagnetic coils melt a cross-sectional area of the object to complete the first layer. [11]

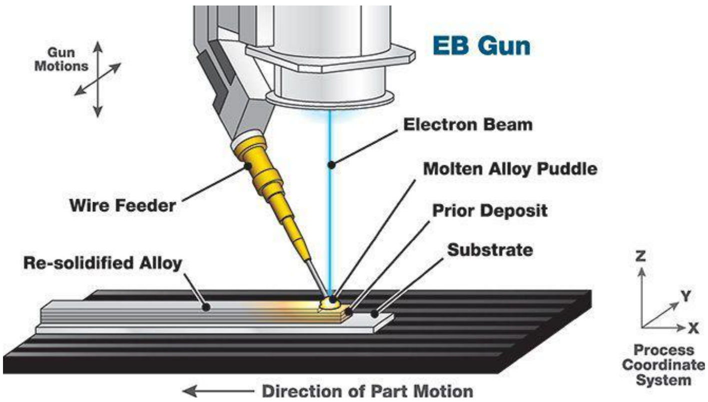

Fig. 4.4.1 Electron Beam Melting Process

The beam is able to rapidly melt areas of the object at the same time, allowing for faster build speeds compare to other sintering prototyping processes as illustrated in figure 4.4.1. Once the layer is complete an automated roller spreads a fresh coat of powder on top of the previous (melted) layer. The process is repeated until a complete 3D object is formed.[17]

V. COMPARISON BETWEEN VARIOUS CLASSIFICATION OF 3- D PRINTING

TABLE5.1 Shows a Comparison between various 3-D printing

Type	Technology	Material	Application
Extrusion	Fused deposition modelling	Thermoplastics (ABS, PLA), Resins	Evaluation of ergonomics, dimensions, and accuracy of a prototype
Light Polymerized	Stereo lithography	Photopolymer	Visual prototypes, conceptual and scale models, rapid tooling, molds and casting patterns and many more.
Granular	Selective laser sintering	Metal powders, Ceramic powders, Aluminium-Filled (PA12-AL)	Aerospace Hardware, Injection Mould Inserts
Granular	Electron beam fabrication	Wires (Titanium alloy)	Jet Engines Rocket / Missile / Propulsion Oil & Gas Equipment Turbine Blades for Energy Production Nuclear Components

VI. APPLICATION

a. TISSUE ENGINEERING

Tissue Engineering is an inter-related and a multi-disciplinary field that integrates the cell behaviour and technique of growing on artificial substrate known as scaffold along with suitable biochemical factors that are required to create artificial tissue and organs or simply to regenerate damaged tissues.[22]

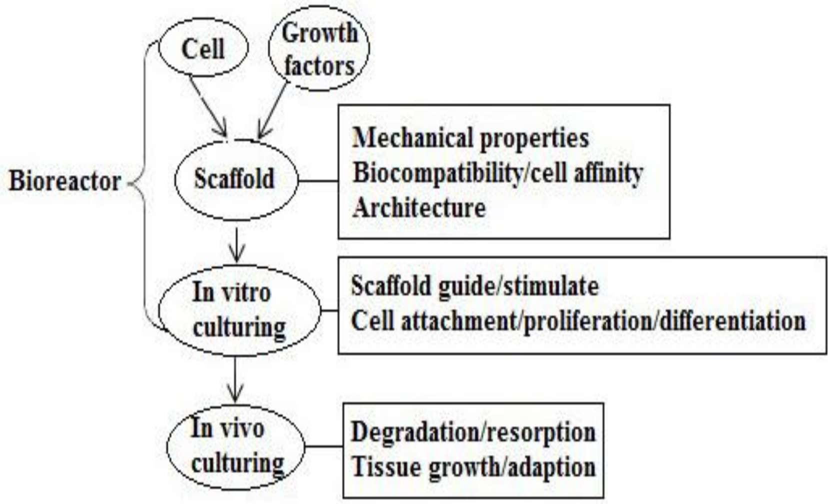

Fig. 6.1.1 Flow diagram of Tissue engineering

It involves the seeding of cells on to a scaffold, which is then cultured invitro to form the matured tissues. Then it is fixed into the body damaged parts such as fractured bone, cartilage or skin as an implant.[21] The natural tissue regeneration process takes place within the scaffold during which the blood vessels infiltrate the structure and the scaffold is degraded slowly while a newly formed tissue is in place as explained schematically in Figure 6.1.1.[16,23] While 3D printed tissue engineering constructs have been developed based on the fundamental characteristics of biodegradability, biocompatibility, and rapid-prototyping, further attention must be given to tissue integration. Host tissue remodelling and integration has often been approached through modification of polymer-cell adhesion and scaffold biodegradability timed with cellular maturation.

b. PROSTHESES

Thanks to 3D printing healthcare applications, orthopedics is moving towards the greater speed in production processes and lowering costs. When prosthetic limbs were first created, they had seemed like something straight out of science fiction, but they have been a boon to countless unique individuals. Recent advancement in 3D printed patient-specific

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prostheses allow a wide range of disabled people affected either by an accident or a genetic deformity to carry on their normal life.[22]

Fig. 6.2.1Prosthetic Leg

With the aid of high-quality imaging technology, 3D printing can create a precise anatomic prosthesis used in various medical applications as shown in figure 6.2.1.[13] This has a made a significant impact on the field of dentistry. And not only humans can benefit from these prostheses even animals got benefited from this example a duck has managed to walk and swim thanks to this advance, and an eagle victim of a shot could recover its peak.[17,23] The ability to produce complex geometries from a range of materials has resulted in AM being adapted at the locations where prosthetics are in contact with a patient. Anatomical Modelling technology has been used to produce everything from prosthetic leg connections that fit comfortably onto a user through to a complex and highly customised facial prosthetic for a cancer patient.

c. ANATOMICAL MODELS

In general, the 3 D printed medical models are made based on virtual digital models obtained from machines such as the computed tomography scanner. However, due to the limited accuracy of CT scanning technology, which is usually 1 millimeter, there are differences between scanned results and the real structure. Besides, the collected data can hardly be printed directly because of some errors in the model. Computer-aided design (CAD), used by engineers to model anything from consumer goods to planes, is incredibly accurate in anatomical modelling but no manufacturing process is perfect.[24] The methodology behind making of anatomical models is illustrated in figure 6.3.1.

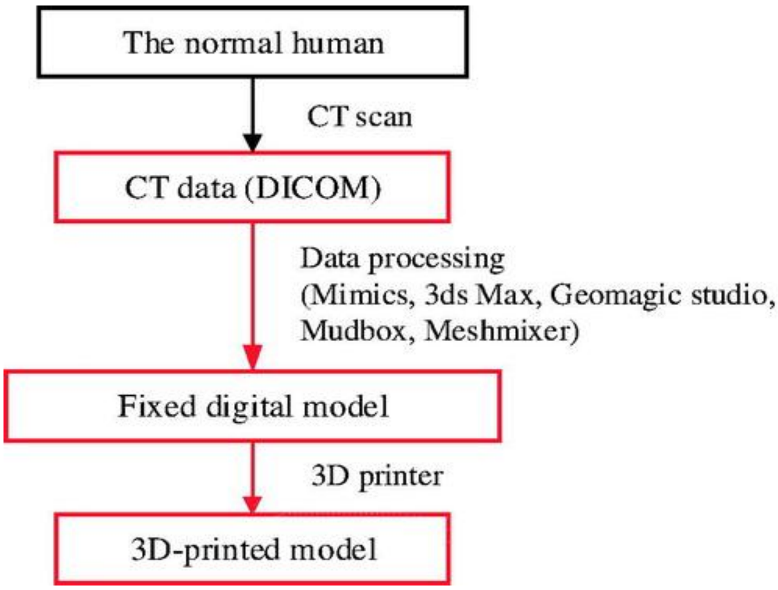

Figure 6.3.1 Flow of Anatomical modelling process

Therefore, engineers specify the required accuracy and resolution, which is different between large parts and small parts. For over 25 years the 3D printing industry has delivered accurate, appropriate resolution printing systems that

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met the demands of engineering customers. Computer-aided design (CAD), used by engineers to model anything from consumer goods to planes, is incredibly accurate in anatomical modeling but no manufacturing process is perfect. [25]

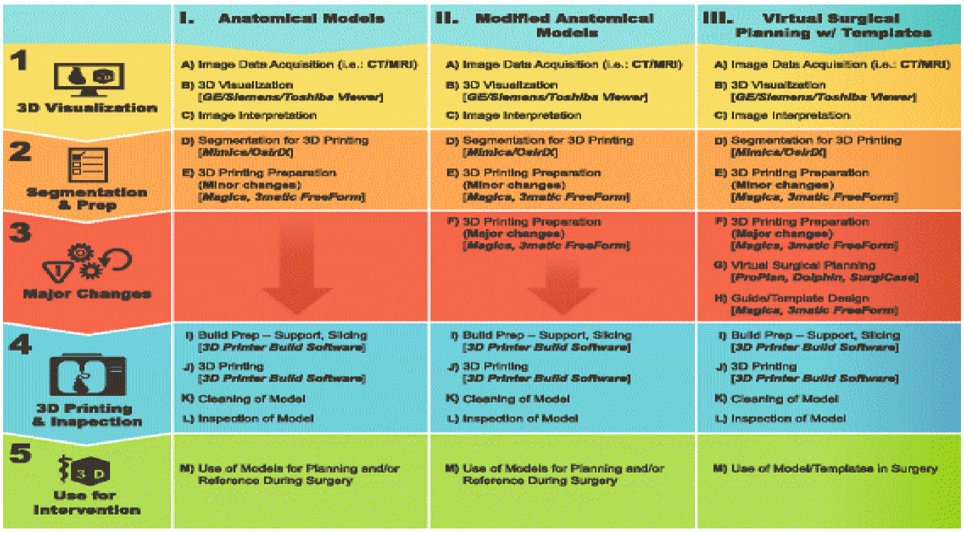

Fig. 6.3.2 Anatomical Model Tpye

The Figure 6.3.2 represents the differences between different anatomical models types used for slightly different applications.

d. CUSTOMIZED IMPLANTS

Custom implants for the reconstruction of craniofacial defects have gained importance due to better performance over their generic counterparts. This is due to the precise adaptation to the region of implantation, reduced surgical times and better cosmesis. Application of 3D modeling in craniofacial surgery is changing the way surgeons are planning surgeries and graphic designers are designing custom implants.[25]

Advances in manufacturing processes and ushering of additive manufacturing for direct production of implants has eliminated the constraints of shape, size, and internal structure and mechanical properties making it possible for the fabrication of implants that conform to the physical and mechanical requirements of the region of implantation.[24]

The process generally is known as reverse engineering in the engineering world starts with acquiring computed tomography (CT)/magnetic resonance imaging 2D image data as digital imaging and communications in medicine

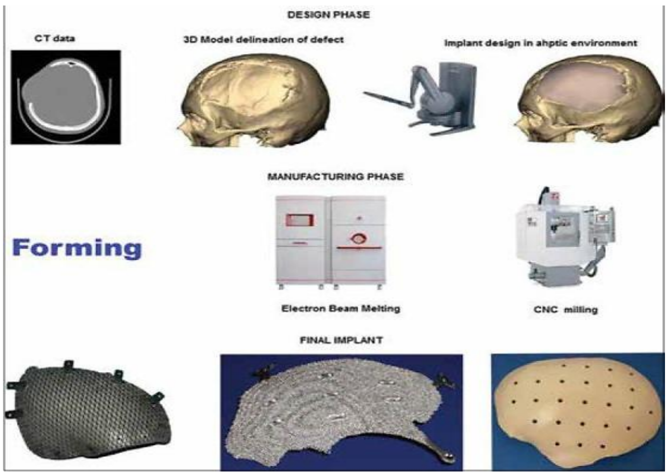

Figure 6.4.1 Customized implant of skull

(DICOM) files. The DICOM data is then processed using the software as MIMICS, Bio build, 3D Doctor to name some to create a 3D model of the anatomy depicting the defect as illustrated in figure 6.4.1. The 3D model file is then

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imported into design software which could be either a haptic based environment as Freeform Geomagic or CAD-based one as 3 Matic from materializing to create the final implant design.[23]

The implant is then manufactured by machining a block of material (subtractive manufacturing) or by adding material layer by layer and fusion of the layers (additive manufacturing). The process of 3D modeling and custom implants is continuously evolving with advancements in the design and manufacturing worlds. The complete process flow for CAD/CAM generated implants is shown in Figure6.4.1.

e. 3-D VASCULARISED ORGANS

Generation of thick vascularised tissues that fully match the patient remains an unmet challenge in cardiac tissue engineering. Here, a simple approach to 3D-print thick, vascularised, and perusable cardiac patches that completely match the immunological, cellular, biochemical, and anatomical properties of the patient is reported.[14] To this end, a biopsy of an omental tissue is taken from patients. While the cells are reprogrammed to become pluripotent stem cells and differentiated to cardiomyocytes and endothelial cells, the extracellular matrix is processed into a personalized hydrogel.[23] Following, the two cell types are separately combined with hydrogels to form bio-inks for the parenchymal cardiac tissue and blood vessels, the investigators wrote.
The ability to print functional vascularised patches according to the patient's anatomy is demonstrated. Blood vessel architecture is further improved by mathematical modelling of oxygen transfer. The structure and function of the patches are studied in vitro, and cardiac cell morphology is assessed after transplantation, revealing elongated cardiomyocytes with massive actinic striation. Finally, as a proof of concept, cellularized human hearts with a natural architecture are printed. These results demonstrate the potential of the approach for engineering personalized tissues and organs, or drug screening in an appropriate anatomical structure and patient-specific biochemical microenvironment.

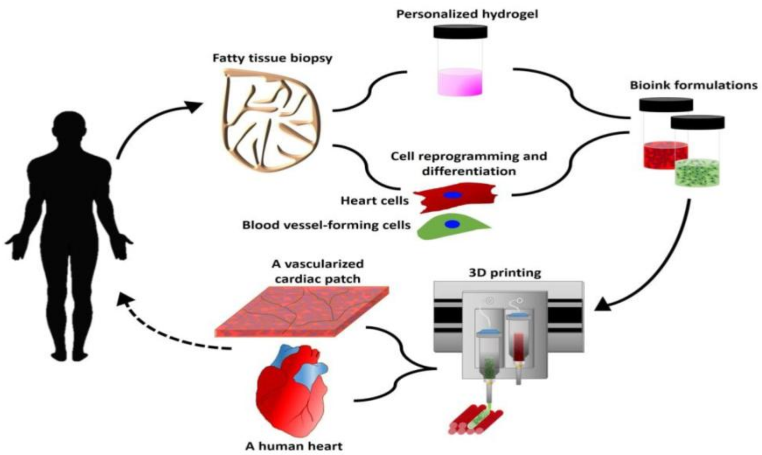

Figure 6.3.2 3D vascularisation process

VII. ADVANTAGE AND DISADVANTAGE OF 3- D PRINTING

Advantage –
a) 100% customizable
b) Short turnaround
c) In-house workflow
d) Affordable
e) Diverse material options
f) Unlimited geometry options

Disadvantage –
a) Struggles with small details
b) Limited build size
c) Support Material
d) Complex Workflow
e) Hard to scale

VIII. SCOPE OF 3-D PRINTING IN HEALTHCARE

When it comes to 3D printing, the sky is the limit. This is mainly because recent advancements in the 3D printing space have made it much more cost-effective than ever. However, although this technology is becoming a daily issue, and experts from many fields closely monitor its evolution. But there are still thousands of people still has no idea of its fantastic potential.[19] One-way 3D printing technology is poised to create better patient outcomes is in creating anatomically and patient-specific models to aid in surgery and medical procedures. 3D printing healthcare applications could have a big impact in the medical field, where extrusion of living cells rather than plastic materials by 3D printers has led to bio-printing.

Creating specialized surgical equipment helps doctors treat the unique needs of their patients more effectively and efficiently. Surgical tools, like forceps, scalpel handles, and clamps, can come out of the printer already sterile–and the materials used are a tenth the cost of stainless-steel equivalents.[16] A 3D impression may also be the hope of many babies born with tracheobronchomalacia, a congenital anomaly that occurs in one of every 2100 new-borns and consists of weakness of the walls of the trachea, producing collapses during respiration or when they cough and is often misdiagnosed as asthma.[18]

Medical technology firms have used printing methods to generate new skin for burn victims, as well as new airway splint implants for toddlers and babies who are suffering from various respiratory issues. 3D printing healthcare applications has allowed a group of medical professors to produce clusters of stem cells. There are many ways to approach this biotechnology, IPS (Induced Pluripotent Stem) cells can be generated without destroying human embryos. embryonic stem cells are those capable of maintaining their pluripotency, that is, of subsequently generating the characteristics that will differentiate them in any other type of cell.[20] India 3-D printer market is projected to cross $79 million by 2021.

IX. CONCLUSION

This paper has presented a ubiquitous review of the application of 3-D printing in medical field. Great progress has been made in the field of medical-oriented 3-D technology, and the manufacturing technology of organ models and permanent implants has become more mature. Researchers have successfully used various methods to enhance the mechanical behaviour of personalized biodegradable scaffold. But still 3D printing in medical field and design needs to think outside the standards for changing the health care. 3D printing just like any other technology has introduced many advantages and possibilities in the field of medicine.

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