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A Critical Review on The Recent Applications of Rapid Prototyping In Bio Medical Implantation

Jasvir Singh,

Lovely professional university, Phagwara 144411,India

ABSTRACT

Rapid prototyping is an additive manufacturing technology which builds three dimensional physical object by adding or depositing the material layer by layer until it reaches upto its final stage. The rapid prototyping has developed a technology which replaces the need of tooling. The additive manufacturing technology has shown its potential capability in many fields of bio-medical applications.

This research reviews focuses on potential capabilities of RP technology for the manufacturing of medical tooling devices, Customized implant design , critical surgical planning ,effective scaffolds for tissue engineering, Porous titanium customized implants, prosthetics and orthotics applications, dental crown patterns and implant structure can be effectively processed using an RP technology.

The RP femoral parts can be evaluated on the basis of their surface roughness, geometrical accuracy and kinematical behavior of the parts could be successfully evaluated.

This paper emphasis on the exploring the process capabilities of various RP techniques, material used under any RP technique,

1.1 Introduction of Rapid Prototyping Process :

Rapid Prototyping Systems: The rapid prototyping (RP) is a additive manufacturing of parts that can automatically construct 3D physical models from CAD data. This technology allows the designers to produce 3D realistic models of their designs quickly. It is much faster than the traditional process of machining that takes a prototype for weeks or months.

1.2 <u>Why a Rapid Prototyping (RP) is an emerging technology of today?</u>

The importance of a RP techniques has exploded the thrust areas for

- ✓ To explore effective communication between manufacturer and customer.
- ✓ To reduce development time of the product.
- ✓ To decrease costly mistakes and encourage sustainable design.

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- ✓ To minimize lost during engineering technical changes of the product.
- ✓ To extend product lifetime by adding the necessary features and eliminating redundant characteristics features during early in the design.
- ✓

The five-step basic procedure is used in all RP techniques:

1. Create a 3D model of the product using computer aided design software packages.
2. Convert the model to .STL format, this format file approximates the shape of a part by triangular facets.
3. Slice the .STL file into thin layers
4. Construct the 3D model of the part layer by layer
5. Post processing:- Clean and finish physical 3D model for dimensional accuracy and surface finish.

1.3 Characteristic of Additive Rapid Prototyping Technologies

Characteristics of Additive Rapid-prototyping Technologies

Process	Supply phase	Layer creation technique	Type of phase change	Materials
Stereolithography	Liquid	Liquid layer curing	Photopolymerization	Photopolymers (acrylates, epoxies, colorable resins, and filled resins)
Multijet/polyjet modeling	Liquid	Liquid layer curing	Photopolymerization	Photopolymers
Fused-deposition modeling	Liquid	Extrusion of melted polymer	Solidification by cooling	Polymers (such as ABS, polycarbonate, and polysulfone)
Ballistic-particle manufacturing	Liquid	Droplet deposition	Solidification by cooling	Polymers and wax
Three-dimensional printing	Powder	Binder-droplet deposition onto powder layer	No phase change	Ceramic, polymer, metal powder, and sand
Selective laser sintering	Powder	Layer of powder	Sintering or melting	Polymers, metals with binder, metals, ceramics and sand with binder
Electron-beam melting	Powder	Layer of powder	Melting	Titanium and titanium alloys, cobalt chrome
Laminated-object manufacturing	Solid	Deposition of sheet material	No phase change	Paper and polymers

Figure 1: characteristic of Additive RP technology, Courtesy: online Google image

The technique begins with the capture, by [12] using the Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) technologies, of inner medical information for a patient. The collected pictures will then be transformed via a Digital Imaging and Medicine (DICOM) folder to a computer assisted design (CAD) model.

Afterwards, various input variables such Slice/layer thickness, printer speed, printer temperature, guide, raster angle, air divide, contours, environmental conditions, type and parameters of the current input flow, laser type and material use, environmental factors, etc. can be chosen on the grounds of the demands of the implant in-terms of desired quality features.

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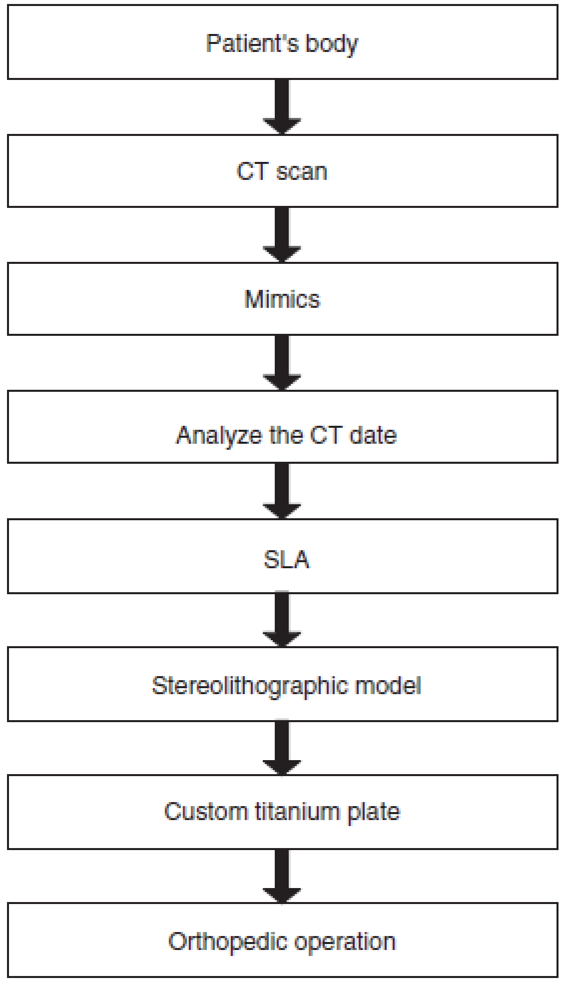

Figure 2 Step process for custom implant design

2.1 Rapid prototyping in Biomedical Implantation:-

As the rapid prototype is widely used for the construction of a 3D [2] physical model, as the techniques was contributing for biomedical applications This research focuses [1] on the (i) Construction of a computer aided design model using software (ii) potential capability of a RP techniques in the field of densitry application. The medical imaging technology such as computerized tomography (CT), Magnetic Resonance Imaging (MRI), and laser digitizing are used to provide the 3D details of the desired anatomy. This 3D model provides the conceptual understanding of a complex anatomic details of the parts which helps in simulation and planning of a complex surgery. The MIMICS software containing MedCAD module which proves to be a bridge between the medical imaging technology and CAD design. The construction of a biomedical active implants such as jaw bone which might get malfunctioned or accidental damage in potential areas of a RP techniques.
The RP processes such as Rapid freeze prototyping (RFP) and multilateral Laser-assisted densification (MMLD) are quite effectively used in this field.

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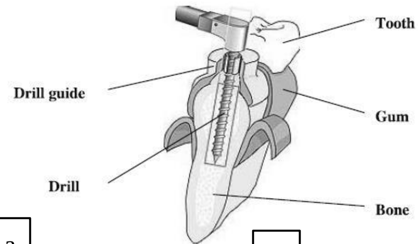
a



b

c

Figure 3a:- Jaw bone model prepared by SLA showcasing drill guide [1]
Fig3b & 3c ;- Fabrication of a dental implant structure [1]

Fig 03: (C) Wax pattern of teeth profile for casting of teeth 3(d)

Fig 3C Fig 3D

The importance [2] of the rapid prototyping technology has been found in the Spine and Pelvis surgery of Trauma, helps in surgical plan resections and to build surgical templates for positioning and guidance of screws and implants during surgery. As per the modern requirement , the surgical pelvis model promotes the accurate placement of computer assisted screw insertion.

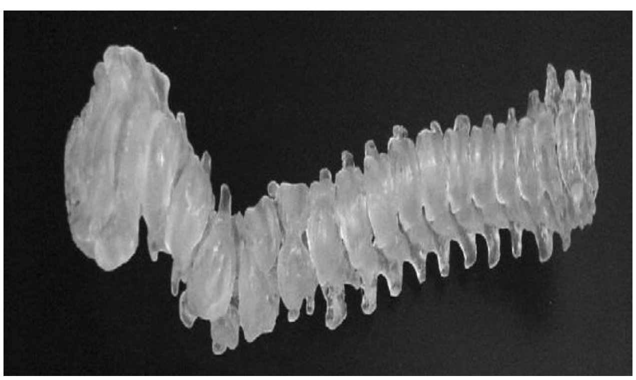


Figure 4: Stereo-lithography model of the Spine[2] .

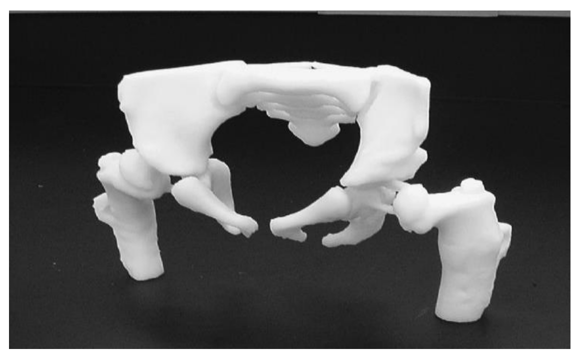


Figure 5: Fused deposition model of the pelvis[2].

The re-constructional craniomaxillofacial surgery and neurosurgery result in the improvement in the understanding of volumetric data ,reduction in the operational errors and communication with the patients.

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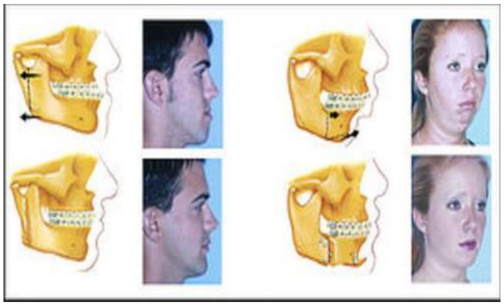

Figure 6: Craniomaxillofacial surgery[2]

Figure 7 - Human skull developed by RP technique[2]

The importance of non destructive **scanning** technology 3**D Computed Tomography** (**CT**) is [3,4] recorded in the manufacturing of a customized titanium plates for carnial defects. As, the titanium is found to be biocompatible, bioactive material, low density, high strength and good corrosion resistance. The spiral 3D scan data were obtained from patient ,the data was transferred by optical disk network to an SUN ultra workstation.

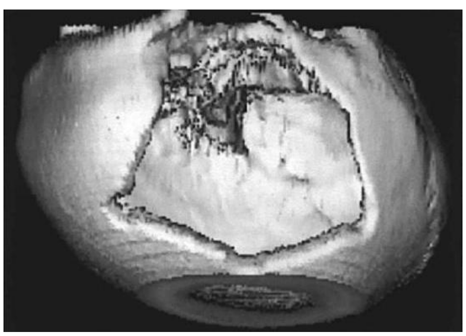

Figure 7: Stereolithography resin model of skull and custom made titanium plate] [3].

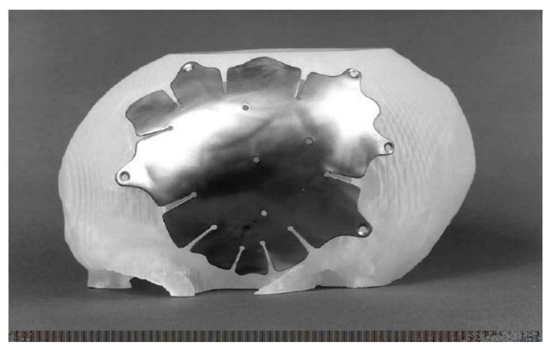

Figure 8: A volume rendered CT of large left side cranial [3]

The different types of rapid prototyping techniques such as Streolithography , Fused deposition modeling and laser sintering techniques were used to made the customized skull body implant. This indicate the potential accuracy of this techniques by implanting the plates with no surgical complications.

The selective rapid laser melting [5] makes it possible to manufacture customized titanium Ti6Al4V alloy mesh scaffolds with high accuracy in external shape and internal pores of 0.48-0.50 mm range within which bone tissue can grow. This alloy has been investigated for scaffolding surfaces which shows a well spread required morphology.

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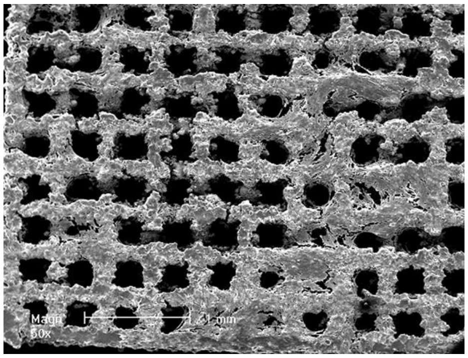

Figure 9- SEM images of osteoblasts[5]

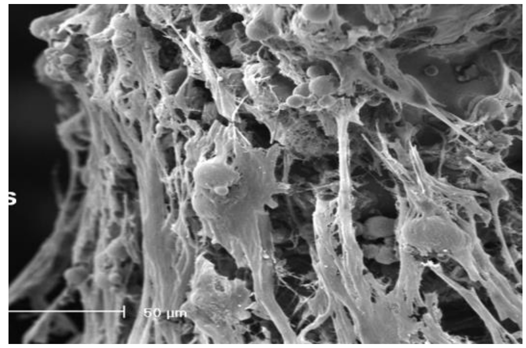

Figure 10- SEM images of Ti6Al4V scaffolding osteoblasts: after seeding for 6 weeks (magnification 1000x) on Ti6Al4V scaffolds [5].

The mechanical and physical properties were examined for customized titanium Ti6Al4V alloy mesh scaffolds.

In the field of artificial knee joint replacement [6] the rapid prototyping technology plays an effective role in obtaining the physical ,mechanical properties , anatomical and biological requirements .In order to have good fixation of the customized bone structure to the host bone and for enhancing the bone in growth implantations, some researchers practice calcium phosphate coating into the metallic implants.

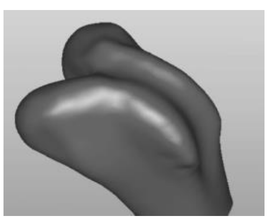

Fig:-11(a) 3D modeling construction

Figure11(b) – Hemi Knee solid model

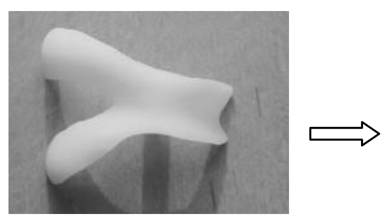

Figure11(c)- RP pattern of Hemi-Knee joint

Figure11(d) - titanium Hemi-Knee joint

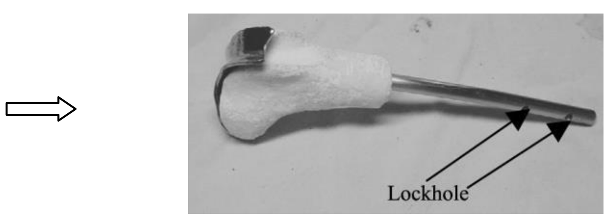

Figure 11e. The fabrication of composite Hemi-Knee joint

The anatomical internal micro-pores and micro-channels were inspected by SEM for sintered porous –bioceramic bone implants , in order to have healthy growth of tissue cells the micro-

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channels (around 300 mm) and micropores (250 mm) were interconnected and uniformly distributed in their vicinity.

In the constructional field of anatomical spine model and guide templates for surgical planning of screw placement , the three dimensional printing technology has proves its capability in this field.

As most of 3.3 million people was suffering from contracting malaria [7], in an estimation around 584000 people die every year as the effective treatment is available, the diagnosis remains a challenging obstacle for the timely prevention of the disease by conventional diagnoster. The aptamer-tethered enzyme capture (APTEC) sensing 3D printed biochips [6] have been effectively created with apps for bacterial identification and virus analysis.

It works by capturing intrinsic enzymes from the samples to produce a blue color in reaction to Plasmodium test positive from the Malaria biomarker Plasmodium falciparum lactate dehydrogenase (PfLDH).

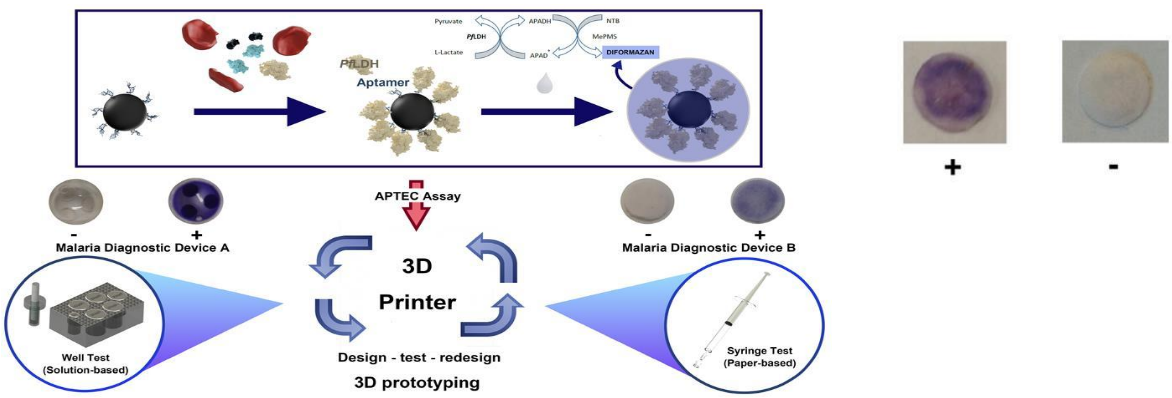

Figure 12 : Biomedical Malarial diagnosis (APTEC) tester

The rapid prototyping [8] have a great significant contribution in the design and manufacturing of bio-medical human implantation. One of the foremost challenge is to generate effective tissue engineering scaffolds for the cell growth.

In the new emerging field of hydrogels were introduced in the tissue engineering, their cross linked polymeric networks capable of containing large amount of water and attractive fluid absorbance properties used in pharmaceutical or biomedical fields due to their biocompatibility and biodegradability. Using production techniques such as ultraviolet stereo lithograph and 2-photon polymerization, gelatin-based hydrogels derived from hydrolysis of collagen preparation of structure comprising photosensitive hydrogel gelatine can be made. Namely 2-hydroxy-1-[4-(2-hydroxyethoxy) phenyl]-2-methyl-1-propanone (Irgacure 2959), phenyl-2,4,6 trimethyl benzoyl phosphinate lithium-LAP and an Eosin Y-based photo initiator are common photo-initiators are used in case of ultraviolet Streo-lithography. The cross linked polymeric structure produced by two-photon polymerization and gamma irradiation permits the encapsulation of bio macromolecules that are most commonly water soluble biodegradability, good fluid absorbance, transparency, mechanically support cells.

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Titanium and its alloy plays a major role in dental and hip joint implantation in such a way to replicate the naturally move within the hip joints while the femalloys [9] as shown in Figure.The Posoral head must be articulating bearings is secured with the stem in relation to the other components.

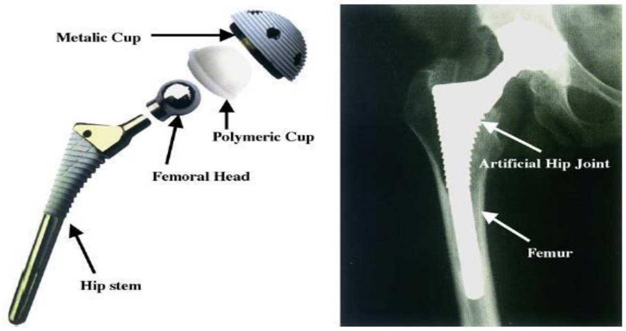

Figure 13 Artificial hip joint

Figure14 Screw-shaped artificial tooth.

Implants of dental care use titanium and its alloys, They are the most used types of implants and can be used as single implants in almost any case to replace an fractured tooth and in cases of partial and total edentulism.

The processing of rapid prototyping is done with the help of selective laser sintering and electron beam melting

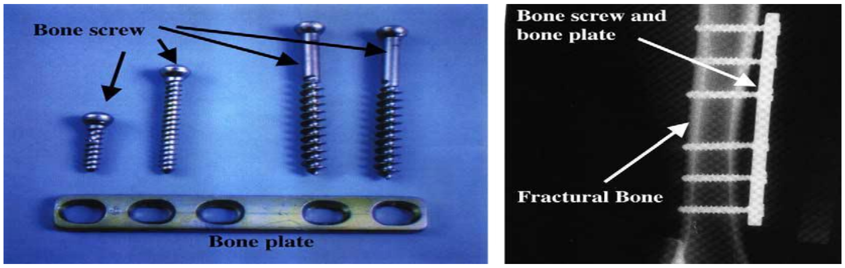

Figure 15 Bone screw and bone plate

The demanding material selection for internal implant fixation is metal, which is highly tolerable biologically,rigid and resistant and good ductility. The ceramics, polymers, carbon composite materials and degradable materials are in the useful range.

In order to have a good sound prosthetic [10] design of knee for implantation, the complex biomechanics kinematical behavior under Vitro test conditions were experimentally investigated. During this evaluation, the surface accuracy and roughness were also determined along with the kinematic behavior. The large number test specimen was prepared from Polyjet 3D printing and Fused Deposition Modeling Rapid Prototyping Techniques.

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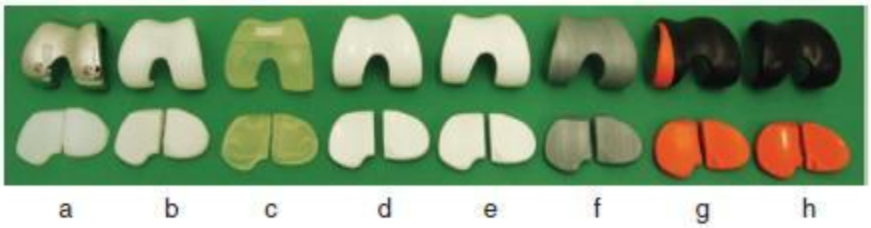

Figure 16:- (A) Reference: CoCr/UHMWPE (ConforMIS); (B) SLS: PA – sanded; (C) PJM: RGD720 – sanded; (D) FDM: ABS – acetone; (E) FDM: ABS – sanded; (F) FDM: PLA – sanded; (G) FDM: ABS+ – sanded; (H) FDM: ABS+ – acetone.

The surface accuracy of the knee specimen is measured by the optical 3D scanner, the surface roughness is measured by a tactile stylus instrument as per the standard. The kinematic analysis was performed on the Meditec knee simulator which is a customized development. The surface accuracy of the femoral component is found to have higher deviation at the support structure with a measuring accuracy of 2mm. The surface roughness is studied with in a tolerance of Ra=0.23 ± 0.07 µm in direction of movement and Ra=0.37± 0.14 µm across the direction of movement. The roughness parameter can be improved by sanding and acetone vapour. The kinematic behavior testing analysis (experiments 1–4) was successfully achieved without any visual damage to the implants, although high active loads with estimated joint forces above 2000 N (sum of applied muscle forces) were applied.

The number of frequency of orthopedic implantation for osteo-plastic and joint replacement surgeries has been increasing every year over a whole worldwide. To have a good implant, it is necessary to overcome the following three major issues [11]:

- Poor degree of functional connection to a load-bearing artificial implant surface between bone surfaces .
- Absence of bone tissue structural anchorage during growth.
- The bio implant get loosed due to bone tissue reabsorption caused by a mechanical rigidity correctness between the implant and bone.

In order to focus on poor bonding between interfaces of the implant and the bone, morphological difference between implant and bone , as these areas need attention.
Porous coating which enhances the fixation of the implant by encouraging bone tissue growth; A diffusion process is used to add metal perforations to a strong surface of the implant. Conductive porous thermal spray technique, sintering techniques of cellular metals, mesh arrays, and creating metallic foams over the implant surfaces. The scaffolds with optimum porosity that imitate the biocompatibility and tissue conductive efficiency of the natural bones have been developed and manufactured. The porous tubes also have a full bone growth potential and guarantee a long-term biological fixation.

The Ti alloys:- alpha-beta titanium alloy was the considerable material choice for applications for more load beared implants. For the Biocompatible scaffolding production, the conventional manufacturing techniques has still several manufacturing challenges and technical limitations such as the number of manufacturing constraints for porous morphology exist for customized shape, size , and internal structure has been removed for biomedical applications by electron

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beam melting (EBM) and selective electron beam melting and selective laser melting (SLM) and implants adapted to the physical and mechanical requirements of the implant area have been developed.

2.1 Shortcomings of the Rapid Prototyping parts used for implanation :

During rapid prototyping techniques, some areas were challenges has been reported such as:

(a) Absence of essential implant surface characteristics.
(b) Poor dimensional accuracy
(c) Low strength of bio implant, low degree of bio-compatibility.
(d) Micro-structural porous scaffolding issues, susceptible to implant corrosion, etc., need to be research focused.

2.2 Future advanced latest applications of Rapid Prototyping Techniques:

From the Critical review of the framework for rapid prototyping in the area of bio-materials, the main problems and challenges were effectively taken under the emerging technique. In medicine and biomedical engineering, the role of rapid prototyping (RP) is growing considerably. The biomedical applications of RP technology are not only tissue engineering, but also the inventions of implantable and other prosthetic such as total joint prostheses and dental prostheses.

In addition, regeneration of bone structure is one of the major tissue engineering techniques. Some advanced biomaterials have also been used, such as the thermo-reversible hydrogels .In orthopedic implants, ceramics are also used. In particular, it is expected that porous composites biomaterials such as HA (Hydro apatite) will be used for regeneration of bone tissue. In addition, Cells themselves are printed or patterned by RP techniques directly. RP attracts great interest in the biomedical field.

Rapid prototyping and manufacturing techniques will also be helpful in the field of the development process of new bio-devices, resolving various technical Problems associated with biological systems interactions of devices, and checking and monitor the design decisions carefully..

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