HUMERUS BONE DEVELOPMENT THROUGH CT/CAD/RPT

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Abstract— Rapid Prototyping Technology is a group of manufacturing processes that enable the direct physical realization of 3D computer models. This technology converts the 3D computer data provided by a dedicated file format directly to a physical model, layer by layer with a high degree of accuracy. This technology is fast developing and is more than competitive to traditional model building techniques considering time and degree of detail. This paper focuses a new method of using data obtained from CT images combined with digital CAD and rapid prototyping model for surgical planning and this new application enables the surgeon to choose the proper configuration and location of internal fixation of plate on humerus bone during orthopaedic surgery. This paper presents the procedure for making a model of humerus bone using rapid prototyping technologies [RPT].

Keywords: Rapid Prototyping (RPT); Computer Tomography (CT); Orthopaedics.

I. INTRODUCTION

Rapid Prototyping Technology (RPT), Solid Freeform Fabrication (SFF) or Layer Manufacturing encompasses a group of production processes. Unlike conventional production processes, which work in a subtractive manner (removing material from a raw block of material giving the final shape of the part), the RPT process builds up parts layer by layer.

The basic steps are the same for all technologies in RP:

1. Design: Create a 3D CAD solid model of the design
2. Converting: Convert the CAD model to STL format
3. Pre-Process: Slice the STL file into thin cross-sectional layers (generated by a dedicated Software)
4. Building process: Construct the model one layer atop another
5. Post-Process: Clean and finish the model

The CAD representation should be done using a 3D solid modeler. These CAD data are derived either from the design process or from a 3D measuring device's point cloud or from computer tomography (CT). Most 3D solid modelers offer an interface to the STL file format that is used as input into the RP machines. The RP software packages slice the 3D model into layers; add support structures where necessary and the actual production can start. Rapid is a bit misleading for the actual manufacturing part of the procedure, as the part production will take hours and days rather than minutes as for the conventional process. What is really rapid is the fast start of the process as the part can be manufactured nearly without any additional programming tasks. Depending on the actual RP process used, more or less time consuming procedures are necessary for cleaning and in some cases post curing the finished parts. In addition to prototypes, RP techniques can also be used to make tooling (R*apid Tooling*) and even production-quality parts (*Rapid Manufacturing*). For small production runs and complicated objects, rapid prototyping maybe the optimal manufacturing process available. Although RPT started with plastic materials, today there is a big choice of metallic and ceramic materials available for almost every major RP process.

This paper covers possibilities of using RP technologies as a multi- discipline area in the field of orthopaedics. Using RP in medicine is a quite complex task which implies a multidisciplinary approach and very good knowledge of engineering as well as medicine; it also demands many human resources and tight collaboration between doctors and engineers. After years of development rapid prototyping technologies are now being applied in medicine for manufacturing dimensionally accurate human anatomy models from high resolution medical image data. The procedure for making humerus bone model using RP technologies is also presented in this paper

II. PROBLEM IDENTIFICATION

Trauma is a major cause of death and disability in both developed and developing countries. The World Health Organization (WHO) predicts that by the year 2020, trauma will be the leading cause of years of life lost for both developed and developing nations. Now a days Trauma is mainly due to increase in population as well as increase in transportation. Due to that there is an increase in accidents that causes bone fracture of human body. Most of the bone fractures in day-to-day life occur in the humerus and femur bones. Machining of ORTHOPAEDIC ALLOY implants, with High Speed Machining, offers advantages, but also has its own disadvantages Titanium is currently used as bone replacements, but the implants are simple geometric approximations of the bone shape. Hence forth there are more chances of mismatches to occur between real bone and implants, which often causes stress concentrations and premature implant failure. More "conventional" machining of Titanium implants with 5-Axis High Speed Machining, which offers some advantages, but also has disadvantages. Mismatches can occur between real bone and implants often causing stress concentrations and premature implant failure.

III. RAPID PROTOTYPING TECHNOLOGIES

The following sections give a short overview on the major RP technologies available today.

3.1 Stereo lithography (SLA)

Stereo lithography (SLA) is the most widely distributed process of RP.A photosensitive liquid, i.e., a resin that solidifies when exposed to light, is in a vat. A laser, emitting ultraviolet light, is placed on top of this vat. The movement of the laser light on the surface of the resin is controlled by a movable mirror, using the data from the CAD system. A building platform within the vat is moved down one layer thickness after the surface layer is solidified (Fig. 3.1).

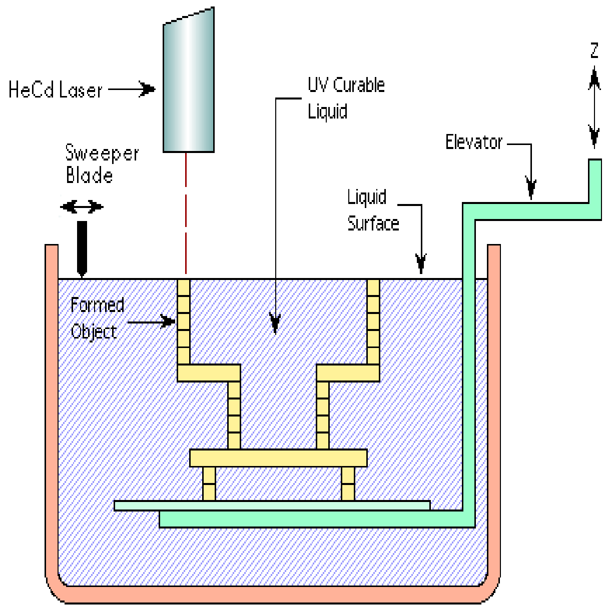

Fig 3.1: Stereo lithography (SLA)

To ensure a even and flat surface, the building platform usually dips deep into the resin, then is raised again so that the solidified surface is at the same level as the liquid's surface and a blade is used to wipe the surface clean. After that the building platform is lowered one layer thickness and the UV light exposure will start as soon as the liquid has set. After the whole part has been completed, it is removed from the vat and the non-solidified resin is drained. This part is called "green part". All processes working with liquid materials for the prototypes have to have support structures for overhangs. The machines control software will include these supports automatically or with human interaction and they will be removed mechanically or chemically after the part has been completed. This green part has to be put into a UV oven for post curing. After this finishing process step the part is stable for handling and further usage.

3.2 Selective Laser Sintering (SLS)

Laser Sintering or Selective Laser Sintering uses fine powders of a wide range of materials to be treated in a nitrogen atmosphere. The powder is heated up to a temperature just below the melting point of the specific material, which usually will take a couple of hours. Then a roller spreads the powder on the building platform. The laser beam then selectively melts the powder and bonds it. As the powder is heated already, the laser needs to elevate the temperature slightly to cause sintering. The temperature gradients in the part remain small. The platform moves down incrementally (one layer thickness) and the process starts again, until the prototype part is finished (Fig. 3.2).After that, the building chamber piston completely moves up and delivers the part. Excess powder is brushed away and final manual finishing may be carried out. No supports are required with this method since overhangs and undercuts are supported by the solid powder bed.

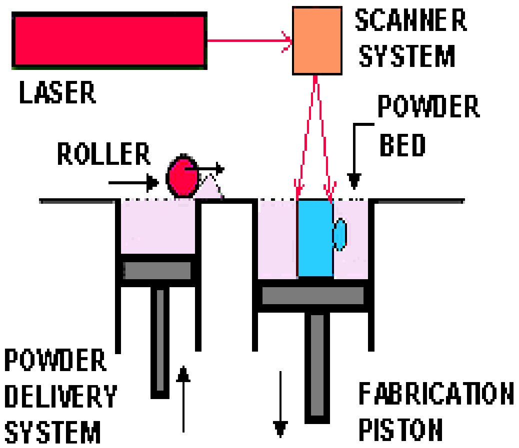

Fig 3.2 Selective Laser Sintering (SLS)

3.3 Fused deposition modeling (FDM)

The FDM process works as follows: First, a 3D solid model exported to the FDM QuicksliceTM software using the (STL) format. The hardware for the FDM machine is represented in (Fig. 3.3). The concept is that an ABS filament (A) is fed through a heating element, which heats it to a semi-molten state. The filament is then fed through a nozzle (B) and deposited onto the partially constructed part. Since the material is extruded in a semi-molten state, the newly deposited material fuses with adjacent material that has already been deposited. The head (C) then moves around in the x–y plane and deposits material according to the part geometry. The platform holding the part then moves vertically downwards in the z-plane to begin depositing a new layer on top of the previous one. After a period of time, the head will have deposited a full physical representation of the original CAD file of the humerus bone.

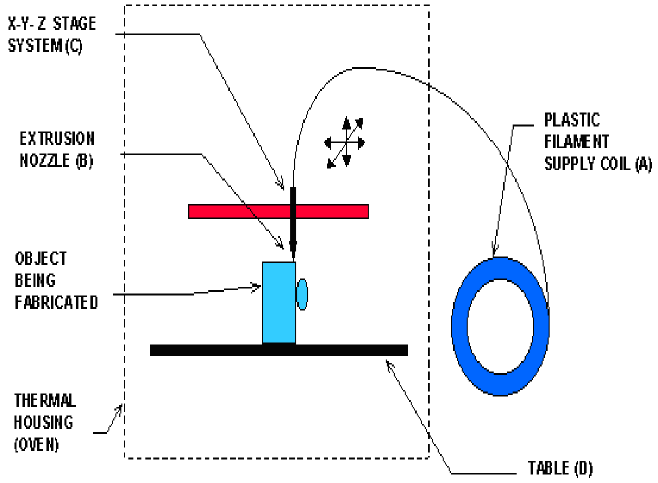

Fig 3.3 Fused deposition modeling (FDM)

IV. MATERIALS

There are varieties of materials which can be used for medical applications of RP.
The material should be selected depends on the purpose of made model (planning procedures, implants, prostheses, surgical tools, tissue scaffold …), demanded properties of material for concrete application and the possibilities of the chosen RP technique. Materials must show biological compatibility.
RP medical materials include:

- Photosensitive resins for medical application (STL);
- Metals (stainless steel, titanium alloys, Cobalt Chromium alloys, other);
- Advanced bioceramic materials (Alumnia, Zirconia, Calcium phosphate- based Bio-ceramics, porous ceramics) for LOM;
- Polycaprolactone (PCL) scaffolds, polymer-ceramic composite scaffold made of Polypropylene-tricalcium phosphate (PP-TCP). PCL and PCL-hydroxyapatite (HA) for FDM, PLGA, starch-based polymer for 3DP, polyetheretherketone-hydroxyapatite (PEEK-HA), PCL scaffolds in tissue engineering for (SLS);
- Bone cement: new calcium phosphate powder binders (mixture of tetra calcium phosphate (TTCP) and beta – tricalcium phosphate (TCP)), Polimethyl methacrylate (PMMA) material, other polymer calcium phosphate cement composites for bone substitutes and implants;
- Many other biocompatible materials.

4.1 Acrylonitrile Butadiene Styrene (ABS)

Acrylonitrile Butadiene Styrene, chemical formula: $((C_8H_8 \cdot C_4H_6 \cdot C_3H_3N)\ n)$ is a common thermoplastic used to make light, rigid, molded products. ABS plastic ground down to an average diameter of less than 1 micrometer is used as the colorant in some tattoo inks. It is a copolymer made by polymerizing styrene and Acrylonitrile in the presence of polybutadiene. The proportions can vary from 15 to 35% Acrylonitrile, 5 to 30% butadiene and 40 to 60% styrene. The result is a long chain of polybutadiene criss-crossed with shorter chains of poly (styrene-co-Acrylonitrile). The nitrile groups from neighboring chains, being polar, attract each other and bind the chains together, making ABS stronger than pure polystyrene. The most important mechanical properties of ABS are resistance and toughness.

V. APPLICATIONS OF RAPID PROTOTYPING IN ORTHOPAEDICS

Production of prototypes for medical modeling (orthopaedics) in general can be classified into two broad categories based on manufacturing process route and type of data available, i.e. designed data and scanned/digitized data. Designed data is data that is created according to a person's idea on computer aided design (CAD) system. For this type of data, the designer has total control to modify, adjust and manipulate his design ideas to serve the functional purpose of his design. Producing models with this type of data is very straightforward and no further data treatment is required. CAD solid model can be directly converted to STL format for use in subsequent rapid prototyping process.

Scanner or digitizer is normally used to capture structures that exist in physical form, either dead or living things, and using surface modeler software, three-dimensional CAD representation is created. For this type of data, the user has limited capability to modify and manipulate the geometry and further processing is required before they can be readily used by rapid prototyping system. For example, further data treatment is needed for Scanned data from computed tomography (CT) and Magnetic resonance imaging (MRI) scanners which capture soft and hard tissue information based on density threshold value. The undesired soft tissue data is removed before it is sent to rapid prototyping machine for fabrication.

Segregating soft tissue data and leaving only hard tissue (i.e. humerus bone) structure can be carried out by applying certain range of density threshold value. This procedure can be a daunting task for complex structure and one has to repeat the procedure many times until satisfactory result is achieved. There are a number of commercial software's such as MIMICS, and Go-build which translate this data to the format required by RP systems. In reverse engineering method, point cloud data for an existing object is captured using coordinate measuring machine or laser digital surface scanner and using surface modeler, this raw data is processed to form three-dimensional model of the object in CAD system.

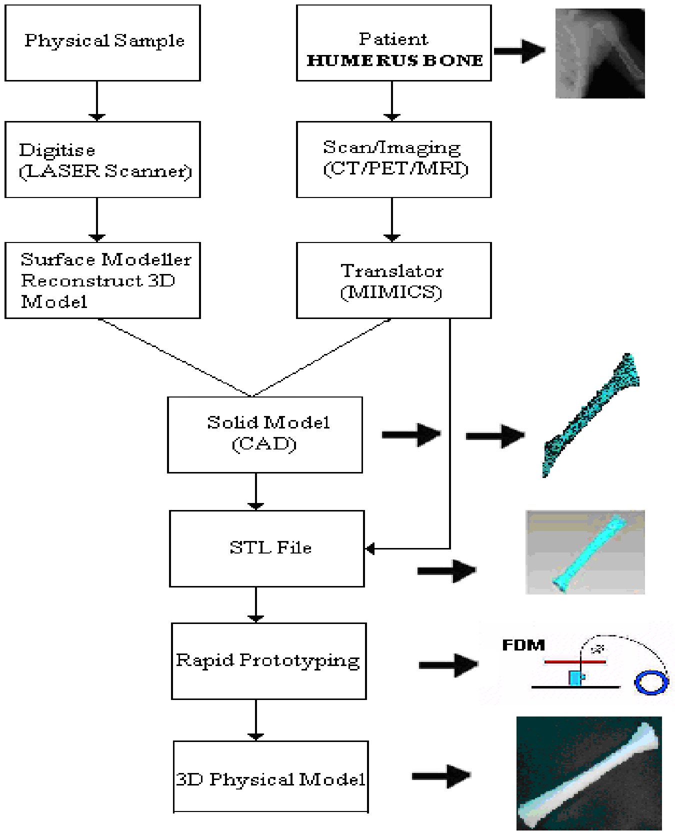

Fig 5.1 Steps Involved In Rapid Prototyping.

5.1 Data acquisition

The morphological data of the humerus bone was collected using the above mentioned CTscanner. A 3D data set was acquired producing 119 sagittal slices with a slice thickness of 1 mm. The reconstructed CT data was transferred to a CD and loaded into the MIMICS software.

5.2 Software

The humerus scanning data and model STL manipulation were processed using MIMICS and MAGICS RP Software (Fig. 5.2.1). .The modeling software is a general purpose segmentation programme for grey value images. This software can generate both the frontal and lateral view from the CT scans (Fig. 5.2.2). From CT data 3D model of humerus bone has been created. RP made a real copy of the bone (Fig. 5.2.3). The real copy was used for planning of orthopedic surgery (Fig. 5.2.4) especially choice of implant type, implant position and application procedure.

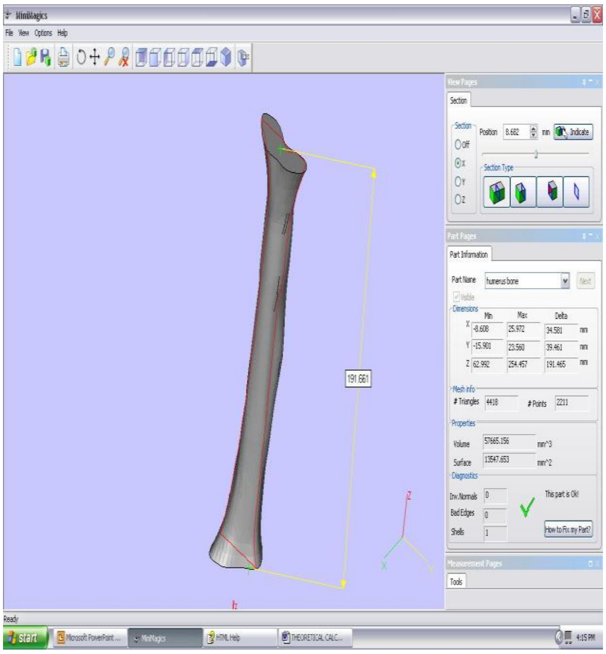

Fig.5.2.1 Humerus bone in MAGICS software.

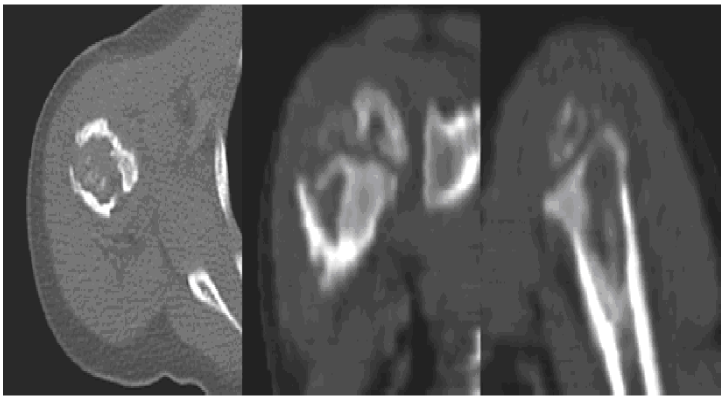

Fig.5.2.2 CT scans of HUMERUS BONE

Fig .5.2.3 RPT Model of Humerus Bone Using ABS material

Fig .5.2.4 Model of Humerus Bone with plate

- **Planning and explaining complex surgical operations.** This is very important role of RP technologies in medicine which enable pre-surgery planning. The use of 3D model of humerus bone helps the surgeon to plan and perform complex surgical procedures and simulations and gives him an opportunity to study the bone structures of the patient before the surgery, to increase surgical precision, to reduce time of procedures and risk during surgery as well as costs (thus making surgery more efficient). The possibility to mark different structures in different colors (due to segmentation technique) in a 3D physical model can be very useful for surgery planning and better understanding of the problem as well as for teaching purpose.

- **Teaching purposes.** RP models can be used as teaching aids for students in the classroom as well as for researchers. These models can be made in many colors and provide a better illustration of anatomy, allow viewing of internal structures and much better understanding of some problems or procedures which should be taken in concrete case. They are also used as teaching simulators.

CONCLUSION

An artificial bone model was fabricated using ABS (Acrylonitrile Butadyine Styrene) by Rapid Prototyping Technology. This technique helps to analyze the actual bone structure and plate fixation can be done more accurately. Due to RP technologies doctors and especially surgeons are privileged to do some things which previous generations could only have imagined. However this is just a little step ahead. There are many unsolved medical problems and many expectations from RP in this field. Development in speed, cost, accuracy, materials (especially biomaterials) and tight collaboration between surgeons and engineers is necessary and so are constant improvements from RP vendors. This will help RP technologies to give their maximum in such an important field like medicine and new technologies can not only improve and replace conventional methods; they also offer the chance for new types of products and developing procedures.

ACKNOWLEDGEMENT

We owe immense gratitude to our principal **Prof.Dr.V.Selladurai,Ph.D.,** Coimbatore Institute of Technology, Coimbatore for his moral support during the course of my Research work. We sincere thanks to **Prof.Dr.G.Sundararaj**,**Ph.D.,** Professor, Department of Production Engineering, P.S.G.College of Technology, Coimbatore and **Prof.Dr.I.Rajendran,Ph.D.,** Professor and Head, Department of Mechanical Engineering, Dr.Mahalingam College of Engineering &Technology, Coimbatore for their valuable guidance and suggestions.

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