ISSN (Online): 2455-7838

SJIF Impact Factor (2017): 5.705

EPRA International Journal of

Research & Development

(IJRD)

Monthly Peer Reviewed & Indexed
International Online Journal

Volume: 3, Issue:11,November 2018

Published By :
EPRA Journals

SJIF Impact Factor: 5.705 Volume: 3 | Issue: 11 | November | 2018 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)

RAPID PROTOTYPING - A KEY TOOL FOR SURGERY

Vaibhav Khola[1]
[1] UG Scholar Department of Mechanical Engineering, Reva Institute of Technology and Management.

Lakshmi B G[2]
[2] UG Scholar Department of Mechanical Engineering, Reva Institute of Technology and Management.

B. Yogesha[3]
[3] Professor, Department of Mechanical Engineering, Malnad College of Engineering, Hassan, Karnataka, India

ABSTRACT

Rapid Prototyping is a promising and powerful technology that has the potential to revolutionize certain spheres in the ever changing and challenging field of medical science, where the automatic construction of physical objects using solid free form fabrication directly from the three dimensional objects. The process involves building of prototypes or working models rapidly in relatively short period of time to create and test various design features, ideas, concepts, functionality and in certain instances outcome with their performance. Henceforth, a profound application in field of medicine such has preoperative planning, surgical training and teaching, inert implants, surgical instruments and special equipment associated with the operations, postoperative guides, long-term supports and aids. The possibilities of medical applications of rapid prototyping are developed and emerging as a key tool for the surgery in the present scenario. This paper provides an insight of the overview how rapid prototyping is useful in the medical field with some of the case studies.

KEYWORDS: *RP-Rapid prototyping, 3-D objects, CAD/CAM, Medical implants, Computer Tomography (CT), DICOM, Segmentation, Medical Modeling, 3D Medical Model.*

1. INTRODUCTION

Medical imaging technologies involve from x-ray radiology to more advanced refined medical imaging modalities such as computerized tomography (CT), magnetic resonance imaging (MRI) and laser digitalizing. These new technologies are able to provide detailed 3-D picture of the anatomy of the area of interest and therefore valuable data for diagnostic and therapeutic usage. Techniques have been developed, together with software and hardware, to represent the data in 3-D on a 2-D screen. Given the visualization provided by sophisticated software packages, the fabrication of physical models may be superfluous. However, the display of a 3-D volume on a 2D screen does not provide surgeons with a complete understanding of the patient's anatomy. Surgeons must learn to interpret the visual information in order to reconstruct mentally the 3D geometry. Recently head mounted displays, stereoscopic glasses and holograms have been employed to compliment the 2D screen to provide a more realistic representation of 3D volume models. Unfortunately, still there is no physical feel of the area of interest like the infection area or the fracture size until the operation is performed. In, short there are several visualization issues that are being addressed but not yet resolved by virtual models.

The construction of physical models is necessary. Physical models are attractive to surgeons because they offer the opportunity to hold the model in hand and view in a natural fashion, thus providing surgeons the direct, intuitive understanding of complex anatomic details which otherwise cannot be obtained from imaging on screen. The use of physical models also creates improved pre-requisites for planning and stimulation of complex surgery. With a physical model the surgeon is able to exercise on the model with the usual surgical tools, enabling him/her to rehearse different surgical plans realistically. Based on this, surgery can be stimulated in a way that is not possible even with the latest visualization technologies. Such an intensive planning of surgical procedures allows the selection of best technical approach. Additionally, the communication between the surgeon and the patient before a complicated surgical procedure can be clearly improved by physical models. And one such technique to produce to physical models is rapid prototyping technique.

Rapid Prototyping is a promising powerful technology that has the potential to revolutionize certain spheres in the ever changing and challenging field of medical science. Rapid Prototyping (RP) is a new forming process which fabricates physical parts layer by layer under computer control directly from 3D CAD models in a very short time [1-2].

The technology is also known by several other names like digital fabrication, 3D printing, solid imaging, solid free form fabrication, layer based manufacturing, laser prototyping, free form fabrication, and additive manufacturing. The history of use of this technique can be traced back to sixties and its foundation credited to engineering Prof Herbert Volcker who devised basic tools of mathematics that described the three dimensional aspects of the objects and resulted in the mathematical and algorithmic theories for solid modeling and fabrication. However the true impetus came in 1987 through the work of Carl Deckard, a university of Texas researcher who developed layered manufacturing and printed 3D model by utilizing laser light for fusing the metal powder in solid prototypes, single layer at a time. The first patent of an apparatus for production of 3D objects by Stereolithography was awarded to Charles Hull whom many believe to be father of Rapid prototyping industry. Emergence of the first RP system in 1988, RP technology has been introduced successfully in the industries of automotive, aerospace, electronics, toy and so on [2-4].

Since its first use in industrial design process, Rapid prototyping has covered vast territories right form aviation sector to the more artful sculpture designing. The use of Rapid prototyping for medical applications although still in early days has made impressive strides. Its use in orthopedic surgery, maxillofacial and dental reconstruction, preparation of scaffold for tissue engineering and as educational tool in fields as diverse as obstetrics and gynecology and forensic medicine to plastic surgery has now gained wide acceptance and is likely to have far reaching impact on how complicated cases are treated and various conditions taught in medical schools.

2. NEED FOR PROTOTYPING IN SURGEORY

It provides detailed 3-D pictures of anatomy of area of interest and gives valuable data for diagnostic and therapeutic usage. The display of 3-D volume in 2-D screen doesn't provide the surgeons with a complete understanding of patient's anatomy. They include low material costs and the possibility that these models can be worked on surgical instruments. Lan et al. [5] developed a tele-service system for RP service bureaus to support the implementation of the Web-based RP manufacturing. Tay et al. [6] introduced the development of a distributed rapid prototyping system via the Internet to form a framework of Internet prototyping and manufacturing for the support of effective product development.

In RP the fabrication of 3-D physical models are directly from CAD, but where as in convectional machining the process is too lengthy which involves various steps. They can build complex shapes in less time than that of conventional machining process which are difficult to build. Rapid Manufacturing technologies potentially offer more anatomical accuracy and better implant fit than traditional manufacturing methods [8].

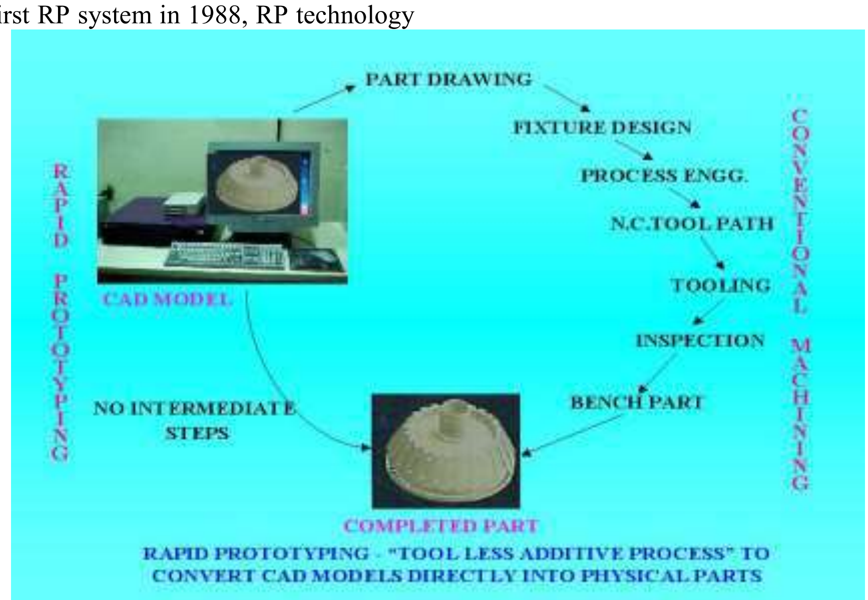

Fig.1.RP in comparison to NC machining

The advantages of RP includes:

- To increase effective communication.
- To decrease development time.
- To decrease costly mistakes.
- To minimize sustaining engineering changes.
- To extend product life time by adding necessary features and eliminating redundant features early in design.

3. MEDICAL APPLICATIONS OF RAPID PROTOTYPING

• **Design and development of medical devices and instrumentation**. This is the field where applications of RP show the best results. It specially applies to hearing aids but also to other surgical aid tools.

• **Great improvements to the fields of prosthetics and implantation**. RP techniques are very useful in making prostheses and implants for years. The ability to quickly fit prosthesis to a patient's unique proportions is a great advantage. The techniques are also used for making hip sockets, knee joints and spinal implants for quite some Medical Applications of Rapid Prototyping 83 time. Both the release of and the improvement of the properties of used materials have had a significant influence on the quality of prostheses and implants made by RP. One interesting example is maxillofacial prostheses of an ear which is obtained by creating a wax cast by laser sintering of a plaster cast of existing ear. Due to RP technologies it is very easy to manufacture custom implants. The made model could be used as a negative or a master model of the custom implant. Many researchers explored new applications of RP in this field.

• **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 medical models helps the surgeon to plan and perform complex surgical procedures and simulations and gives him an opportunity to study the bony 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. This is especially important in cancer surgery where tumor tissue can be clearly distinguished from healthy tissue by different color. Surgical planning is most often done with stereo lithography (SLA) where the made model has high accuracy, transparency but limited number of colors and 3DP (for more colored models, presentation of FEA results).

• **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.

• **Design and manufacturing biocompatible and bioactive implants and tissue engineering.** RP technologies gave significant contribution in the field of tissue engineering through the use of biomaterials including the direct manufacture of bioactive implants. Tissue engineering is a combination of living cells and a support structure called scaffolds. RP systems like fused deposition modeling (FDM), 3D printing (3-DP) and selective laser sintering (SLS) have been proved to be convenient for making porous structures for use in tissue engineering. In this field it is essential to be able to fabricate three-dimensional scaffolds of various geometric shapes, in order to repair defects caused by accidents, surgery, or birth. FDM, SLS and 3DP can be used to fabricate a functional scaffold directly but RP systems canal so be used for manufacturing a sacrificial mold to fabricate tissue-engineering scaffolds.

4. MATERIALS USED

There are varieties of materials which can be used for medical applications of RP. The type of material to be selected depends on the purpose of model (planning procedures, implants, prostheses, surgical tools) 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); Stereo lithography (SLA)

• Metals (stainless steel, titanium alloys, Cobalt Chromium alloys, other); Selective Laser Sintering (SLS)

• Advanced bio ceramic materials (Alumina, Zirconia, Calcium phosphate-based Bio ceramics, porous ceramics) for Laminated object Manufacturing (LOM)

• Poly-caprolactone (PCL) scaffolds, polymer-ceramic composite scaffold made of polypropylene tri-calcium phosphate (PP-TCP). PCL and PCL-hydroxyapatite (HA) for FDM, PLGA, starch-based polymer for 3DP, poly-ether ether-ketone-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 – tri-calcium phosphate (TCP)), Poly-methyl methacrylate (PMMA) material, other polymer calcium phosphate cement composites for bone substitutes and implants;

• Many other biocompatible materials. In this class Rapid Manufacturing technologies are utilized to possible anatomic personalization of a device or corresponding element. Prosthetic sockets can be manufactured using rapid prototyping technology. Creating the socket has traditionally been labor intensive and it usually takes two to three days to make one socket. Using CAM systems and rapid manufacturing technologies the time is reduced to less than 4 hours [10].

In cochlear implant surgery rapid manufactured drill guides have been used and these reduced operative time and overall cost [11].

5. ILLUSTRATIVE CASES

Case 1 – Ace-tabular Fracture

Mr. Y, a 29-year-old male, with a history of fall from a 20-ft height presented in the casualty department with multiple fractures. There was no history of head injury and his spine screening was normal. Other fractures included grade IIIb open fractures of the lower third of the right humerus, left volar Barton fracture, and a bi-columnar fracture of the acetabulum on the left side. His vitals were stable and after appropriate stabilization, a CT scan of the pelvis was taken.

The CT scan showed a vertical displaced fracture involving the iliac blade starting 3 cm below the iliac crest and extending forward, reaching up to the ace-tabular roof and tri-radiate cartilage, involving both anterior and posterior columns. There was a mild protrusion of the femoral head and the fracture line extension was present till the superior pubic rami [Figure 6A, B, and C]. [7]

Fig.6. Preoperative X-rays – Judet'sobdurate view. [7]

Fig7. RP Model of fractured acetabulum [7]

Case 2: Calcaneal Fracture

A 16-year-old male was admitted with a history of fall from a 12-ft height 2 days after injury. He had sustained a type IIB Sanders' classification closed calcaneal fracture. Spine screening and other examinations were normal. After the swelling decreased as proven by the appearance of wrinkles on day 8, surgery was planned. A CT scan was done [FIG 8] and a 3D model of the calcaneum was made using the RP technique. The 3D model showed the fracture lines clearly and helped plan the surgery [Figure 9]. [7]

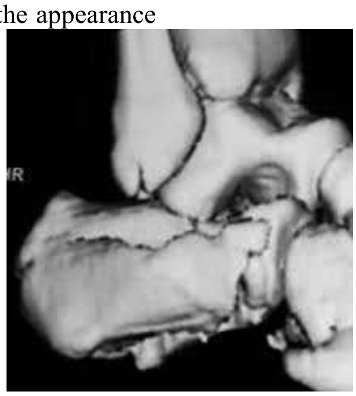

Fig.8. Fracture Calcaneum CT scan image reconstruction [7]

Fig.9. Fracture Calcaneum Rapid prototype Model [7]

Case 3: Complex Spinal Deformity

A 3 year old child with scoliosis and D6 hemi vertebrae who was posted for a corrective surgery a 3 D Model was created (Fig10, 11) using Rapid Prototyping technique. The model helped understand the complex anatomy and planning hemi-vertebrae resection anteriorly. The surgeon felt it immensely useful in providing preoperative rehearsal with 360 degree visualization of pedicles and planning entry point, screw trajectories and screw length. [7]

Fig.10. X-ray picture of congenital Scoliosis [7]

Fig.11. RP model of congenital scoliosis [7]

As a vehicle for visualization rapid prototyping models may also serve as important learning tools to young surgeons for practicing complex surgery which have a steep learning curve. The models of various conditions and fracture patterns may also provide students an opportunity to understand the pathology and classifications better. This would be in some way similar to the use of cadaveric dissection and bone models to teach normal anatomy. These models can be made in different colors to better illustrate various anatomical structures (Fig 12). [7]

Fig.12 Didactic model for teaching students the anatomy and mechanics of the ankle joint, differently colored bone help easy identification and better understanding of the concepts [7]

Case 6: Total hip replacement

Complex adult reconstruction like those requiring total hip replacement in case of defects on the ace-tabular side require extensive planning and also various customized inventory. 3d modeling helps to plan and also design additional implants. The case described here had ace-tabular defect secondary to hip infection (Fig. 13, 14). A 3D model using RP was made and an ace-tabular cage/ anti-protrusion ring designed for the same. The surgery in this case went smoothly and surgeon felt that the time required and inventory on table was also reduced.

Fig.13. RP model showing ace-tabular defect in patient scheduled to undergo total hip Replacement [7]

6. REVERSE ENGINEERING IN MEDICAL FIELD

Reverse Engineering is the systematic evaluation of a product with purpose of replication. It involves

- Design of new part
- Copy of existing part
- Recovery of a damaged or broken part

Reverse engineering in medical field finds its applications in

- Orthopedic, dental & reconstructive surgery.
- Imaging, modeling and replication (as a physical model) of a patient's bone structure.
- Models can be viewed & physically handled before surgery, benefitting in evaluation of procedure & implant fit in difficult cases.
- Less risk to patient and reduced cost through saving in theater time.

.

Fig.14. RP model of acetabulum as seen from front [7]

7. CONCLUSION

RP technologies are definitely widely spread in different fields of medicine and show a great potential in medical applications. Various uses of RP within surgical planning, simulation, training, production of models of hard tissue, prosthesis and implants, biomechanics, tissue engineering and many other cases open up a new chapter in medicine. Due to RP technologies doctors and especially surgeons are privileged to do some things which previous generations could only have imagined. An example is treatment of dental malocclusion by rapid manufacturing a mold for a series of clear and removable appliances [9].

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 radiologists, 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.

Recent research has led to the development of the RP process building and improving upon artificial bone implants which are strong enough to support a new bone yet, at the same time, porous enough to be absorbed and replaced by the body. This will help in using RP for replacing severely injured bones. It is a very significant discovery in medicine and the first step on the way to making other complex human organs. There are also many unexplored possibilities of using RP in different fields of medicine. Further development in RP in tissue engineering requires the design of new materials, optimal scaffold design and the input of such kind of knowledge of cell physiology that would make it possible in the future to print whole replacement organs or whole bodies by machines. There are also many new trends of applying RP in orthopedics, oral and maxillofacial surgery and other fields of medicine.

ACKNOWLEDGEMENT

We the authors would like to thank all my teachers for lending their valuable suggestion and support for the preparation of this technical paper on rapid prototyping.

REFERENCES

1. *Medical Applications of rapid prototyping-Three dimensional bodies for planning and implementation of treatment and for tissue replacement- Article in Finnish.*
2. *D. T. Pham, S. S. Dimov, Rapid Manufacturing: the Technologies and Applications of Rapid Prototyping and Rapid Tooling, Springer,London, 2001.*

3. *P. F. Jacobs, Stereo lithography and other RP&M Technologies: From Rapid Prototyping to Rapid Tooling, ASME Press, New York, 1996.*
4. *D. T. Pham, R. S. Gault, A comparison of rapid prototyping technologies. International Journal of Machine Tools & Manufacture, Vol. 38, 1998, pp. 1257– 1287.*
5. *H. B. Lan, K. S. Chin, J. Hong, Development of a teleservice system for RP service bureaus. Rapid Prototyping Journal, Vol. 11, No. 2, 2005, pp. 98-105.*
6. *F. E. H. Tay, Y. P. Khanal, K. K. Kwong, Distributed rapid prototyping - a framework for internet prototyping and –manufacturing. Integrated Manufacturing Systems, Vol. 12, No. 6, 2001, pp. 409–415.*
7. *Vaibhav bagaria, Darshana Rasalkar, Shalini Jain Bagaria, Jami ilyas "Medical applications of Rapid Prototyping- A new horizon"*
8. *Janssens M. & Poukens J. 2007. Rapid Technologies in medi-cine: What can, can't be done and why, International Con-ference on Competitive Manufacturing, 31 January - 2 Feb-ruary 2007 Stellenbosch, South Africa.*
9. *Miller J.R. & Derakhshan M. 2002. The Invisalign System: Case report of a Patient with Deep Bite, Upper Incisor Flar-ing, and Severe Curve of Spee, Seminars in Orthodontics, 2002, vol. 8, no. 1.*
10. *Ng P., Lee P.S.V. & Goh J.C.H. 2002. Prosthetic sockets fabri-cation using rapid prototyping technology, Rapid prototyping journal, 2002, vol. 8, no. 1.*
11. *Labadie R.F., Noble J.H., Dawant B.M., Balachandran R., Ma- jdani O. & Fitzpatrick J.M. 2008. Clinical Validation of Percutaneous Cochlear Implant Surgery: Initial Report, The Laryngoscope, June 2008, vol. 118, issue.*