FACTA UNIVERSITATIS
Series: **Mechanical Engineering** Vol. 5, N° 1, 2007, pp. 79 - 85

MEDICAL APPLICATIONS OF RAPID PROTOTYPING

UDC 620.162 : 681.5.017

Jelena Milovanović*, Miroslav Trajanović

Faculty of Mechanical Engineering, Niš, Aleksandra Medvedeva 14, 18000 Niš
*E-mail: jeki@masfak.ni.ac.yu

Abstract. *The most interesting and challenging applications of rapid prototyping technologies are in the field of medicine. RP medical models have found application for planning treatment for complex surgery procedures, training, surgical simulation, diagnosis, design and manufacturing of implants as well as medical tools. This paper explores and presents the procedure for making medical models using RP, medical rapid prototyping technologies application in different fields of medicine and the future trends in this area.*

Key words: *Rapid Prototyping (RP), Computer Tomography (CT), DICOM, Segmentation, Medical Modeling, 3D Medical Model*

1. INTRODUCTION

As it is well known, the term "rapid prototyping" refers to a number of different but related technologies that can be used for building very complex physical models and prototype parts directly from 3D CAD model. Among these technologies are stereolithography (SLA), selective laser sintering (SLS), fused deposition modeling (FDM), laminated object manufacturing (LOM), inkjet-based systems and three dimensional printing (3DP). RP technologies can use wide range of materials (from paper, plastic to metal and nowadays biomaterials) which gives possibility for their application in different fields. RP (including Rapid Tooling) has primary been developed for manufacturing industry in order to speed up the development of new products. They have showed a great impact in this area (prototypes, concept models, form, fit, and function testing, tooling patterns, final products - direct parts). Preliminary research results show significant potential in application of RP technologies in many different fields including medicine.

This paper covers possibilities of using RP technologies as a multi- discipline area in the field of medicine. 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.

Received June 06, 2007

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 medical models using RP technologies is also presented in this paper.

2. RP MEDICAL MODEL PRODUCTION

The procedure for making 3D medical models using RP technologies implies few steps:
- 3D digital image;
- Data transfer, processing and segmentation;
- Evaluation of design;
- RP medical model production;
- RP medical model validation.

2.1. 3D Digital Image

3D digital image can be obtained by using computer tomography - CT scanner or MRI data (see Fig. 1). These imaging technologies are used for modeling internal structures of human's body. Medical models made from this data must be very accurate and because of this they require a spiral scanning technique which allows to do full volume scanning. This makes possible to generate a high number of slices (recommended thickness 1-2 mm) and what is very important, the pixel dimension in each slice could be reduced depending on each case. Most CT and MRI units have the ability of exporting data in common medical file format - DICOM – digital imaging and communication in medicine.

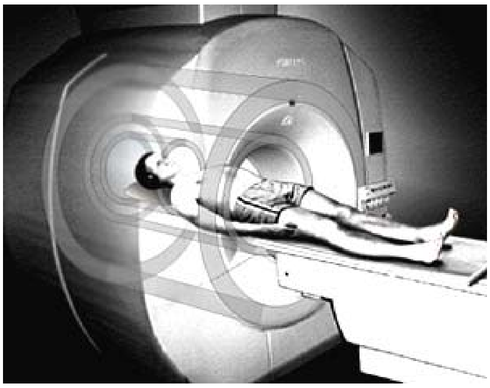

Fig. 1 MRI unit

2.2. Data Transfer, Processing and Segmentation

After saving CT or MRI image data, they should be transferred to RP or RE laboratory. The next step is processing these data, which is a very complex and important step, that the quality of the final medical model depends on.

For this step engineers need software package (Mimics, 3D Doctor) in which they can make segmentation of this anatomy image, achieve high resolution 3D rendering in different colors, make 3D virtual model and finally make possible to convert CT or MRI scanned image data from DICOM to .STL (Stereolithography) file format, which is universally accepted RP file format (see Fig. 2). These software packages allow making segmentation by threshold technique, considering the tissue density. In this way, at the end of image segmentation, there are only pixels with a value equal or higher than the threshold value.

The virtual model of internal structures of human's body, which is needed for final production of 3D physical model, requests very good segmentation with a good resolution and small dimensions of pixels. This demands good knowledge in this field which should help engineers to exclude all structures which are not the subject of interest in the scanned image and choose the right region of interest ROI (separate bone from tissue, include just part of a bone, exclude anomalous structures, noise or other problems which can be faced). Depending on complexity of the problem this step usually demands collaboration of RE engineers with radiologists and surgeons who will help to achieve good segmentation, resolution and a finally accurate 3D virtual model.

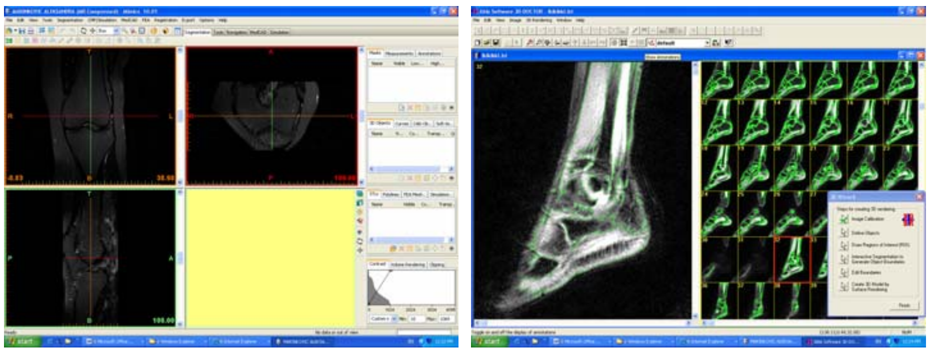

Fig. 2 Commercial Software Packages for Image Segmentation

2.3. Evaluation of Design

This step depends on a case-to-case basis. Sometimes the created model is directly used as an input for RP machine (biomodels).

For making surgical tools, incorporating other objects (fixation devices, implants), bone replacements, producing patterns for making fixtures or templates or other complex problems in different fields of medicine, this virtual model in IGES or STL format is processed using some CAD package (Pro Engineer, Catia). This is necessary for evaluation of design, quality of the made model, checking possible errors or other important steps which depends on the concrete case.

Surgeons have a very important roll in validation of the created virtual model. It is even more important in some cases of errors which are made because of the misunderstanding of anatomical structures by engineers or because of some disturbances in the scanned images.

After this step 3D virtual model is ready for production.

2.4. RP Medical Model Production

This step implies choosing the right RP technology according to the purpose of model itself as well as demanding accuracy, surface finish, visual appearance of internal structures, number of desired colors in the model, strength, material, mechanical properties, etc.

Finally 3D virtual model in STL format should be inputted into the RP commercial software for production of 3D physical model (see Fig. 3).

The quality of physical model is influenced, in the first place, by quality of input STL file but also by orientation of the model in RP machine and by choosing the right parameters for building the model in the same machine.

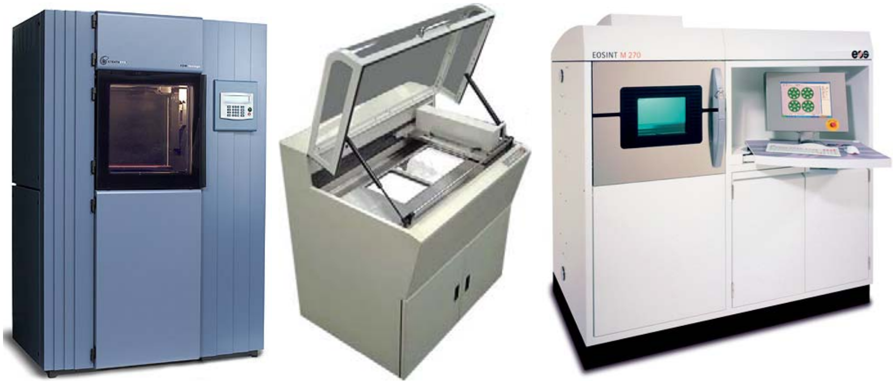

Fig. 3 Different RP Systems

2.5. RP Medical Model Validation

When the RP medical model is manufactured it should be validated by surgeons. If there are no errors the model is ready for application.

3. RP Applications and Materials

No single rapid prototyping technology is dominant in medical applications and they can be used in the most fields of medicine. This paper will summarize the most common application of these technologies.

3.1. RP Applications

- **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

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 presurgery 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 stereolithography (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 can also be used for manufacturing a sacrificial mould to fabricate tissue-engineering scaffolds.

3.2. Materials

There are varieties of materials which can be used for medical applications of RP. Which 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 bioceramics, 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 tetracalcium 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.

3.2. Recent and Future Trends

Resent 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.

4. 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.

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.

REFERENCES

1. Fergal J. O'Brien, David Taylor, T. Clive Lee, 2007, *Bone as a composite material: The role of osteons as barriers.to crack growth in compact bone,* International Journal of Fatigue 29, pp.1051–1056.
2. Robiony, M., costa, F., Bazzocchi, M., Bandera, C., Felice, M., 2007, *Virtual Reality Surgical Planning for Maxillofacial Distraction Osteogenesis: The Role of Reverse Engineering Rapid Prototyping and Cooperative Work,* Journal of Oral and Maxillofacial Surgery, pp. 1198-1208.
3. Bibb, R., 2006*, Medical modeling: The application of advanced design and development techniques in medicine,* University of Wales, UK, 312 p.
4. Gibson, I., 2006, *Advanced Manufacturing Technology for Medical Applications: Reverse Engineering, Software Conversion and Rapid Prototyping (Engineering Research Series (REP)),* Wiley, 254 p.
5. Ngan, E., Rebeyka, I., Ross, D., Hirji M., Wolfaardt, J., Dent, M., Seelaus, R., Grosvenor, A., Noga, M., *The rapid prototyping of anatomic models in pulmonary atresia, 2006,* The Journal of Thoracic and Cardiovascular Surgery*,* pp. 264-269.
6. Milovanović, J., Trajanović, M., Stojković, M., 2005, *Possibilities of using selective laser melting for tire mold manufacturing*, Proceedings, 2nd International Conference on Manufacturing Engineering Icmen, Kallithea of Chalkidiki, Greece, pp. 187-193.
7. Winder J., Bibb, R., 2005, *Medical Rapid Prototyping Technologies: State of the Art and Current Limitations for Application in Oral and Maxillofacial Surgery, Journal of Oral and* Maxillofacial Surgery, pp. 1006-1015.
8. Woesz, A., Rumpler, M., Stampf, J., Varga, F., Fratzl-Zelman, N., Roschger, P., Klaushofer, K., Fratzl, P., *Towards bone replacement materials from calcium phosphates via rapid prototyping and ceramic gelcasting*, 2005, Materials Science & Engineering Cpp, Volume 25, Issue 2, pp. 187-193.
9. Gibson, I., Cheung, L.K., Chow, S.P.,. Cheung, W.L., Beh, S.L., Savalani, M., Lee, S.H., 2006, *The use of rapid prototyping to assist medical applications*, Rapid Prototyping Journal, 12/1, pp. 53–58.
10. D. Ma, F. Lin, C. K. Chua, 2001, *Rapid Prototyping Applications in Medicine. Part 2: STL File. Generation and Case Studies*. The International Journal of Advanced Manufacturing Technology, 18, pp.118–127.

PRIMENE RAPID PROTOTYPING TEHNOLOGIJA U MEDICINI

Jelena Milovanović, Miroslav Trajanović

Jedno od najinteresantnijih i najizazovnijih polja primene RP tehnologija je u medicini. RP medicinski modeli su našli primenu u planiranju kompleksnih hirurških intervencija, simulaciji, projektovanju i izradi implanata, medicinskih uređaja, hirurških pomoćnih alata, kao i u inženjeringu tkiva. U ovom radu je detaljno prikazana procedura pri proizvodnji medicinskih modela korišćenjem RP tehnologija, primena RP tehnologija u različitim granama medicine kao i budući trendovi i potrebe razvoja istih.

Ključne reči: *rapid prototyping (RP), kompjuterska tomografija (CT), DICOM, STL, segmentacija, 3D medicinski model*