International Journal of Computer Applications (0975 – 8887)
Volume 119 – No.17, June 2015

Computerized 3D Modeling for Rapid Artificial Bone Substitute Manufacturing

P.M.P.C. Gunathilake
Department of Statistics and Computer Science, Faulty of Science, University of Peradeniya, Sri Lanka

Y.P.R.D. Yapa
Department of Statistics and Computer Science, Faulty of Science, University of Peradeniya, Sri Lanka

A.J. Pinidiyaarachchi
Department of Statistics and Computer Science, Faulty of Science, University of Peradeniya, Sri Lanka

J.V. Wijayakulasooriya
Department of Electrical and Electronic Engineering, Faulty of Engineering, University of Peradeniya, Sri Lanka

R. Ranaweera
Department of Electrical and Electronic Engineering, Faulty of Engineering, University of Peradeniya, Sri Lanka

ABSTRACT
Rapid bone substitutes manufacturing is highly important due to a vast number casualties are stepped to the society as a result of mainly traffic accidents, natural disasters and civil wars. Though casualties are grouped into several categories, a considerable number of patients is fallen into the bone associated injuries. It is also notable that especially the traffic related accidents and natural disasters may occur in populated regions. Due to financial reasons all the hospitals in the developing countries cannot maintain sophisticated scanning equipments along with their software solutions. Therefore having a lightweight software solution that facilitates bone profiling will be beneficial for patients and it also helps surgeons to prepare a care plan depending on the disorder. However, the artificial tools that are inserted to the human body can vary upon the injury. Hence, they should be highly customizable. Though computerized 3D modeling started around two decades ago, a few tools are available to assist surgeons in such situations. The available applications and techniques have limited functionalities thus, the manufactured bone grafts may not perfectly be suited to the lesion or injury. In this paper we propose a minimally invasive procedures to model bone grafts. In which, quality control methods for noise removals and 3D data compression mechanisms are coupled to the software solution that runs even on typical personal computer systems. The end result of the 3D modeled bone can be employed to extract the cavity, clip regions of interest and even to test the manufactured bone graft before the surgical procedure. Thereby, the process of manufacturing the prosthetic and the clinical procedures will be efficient and reliable.

General Terms
3D modeling, bone graft

Keywords
Bone graft, artificial bone substitute, bone measurement

1. INTRODUCTION
Medical Image Processing is used to construct the features of the images obtained through various modalities such as Computed Tomography (CT), X-ray, Magnetic Resonance Imaging (MRI) and Ultra Sound which are not obvious and profound. The set of images obtained from these modalities are used for clinical purposes to diagnose pathological conditions. Each of these techniques has unique properties; for example CT scan may use to diagnose bone related disorders and injuries. This produces a stack of two dimensional images that are not effective for extensive clinical examinations as they are individual image slices. Therefore, it is necessary to integrate these image slices to establish a complete treatment plan.

The images acquired using CT modalities are the best suited to produce bone grafts as they highlight bone tumors and fractures. A plane radiograph represents the additive effect of all the tissues and bones of the organ being radiographed. The CT images are obtained using a wide X-ray beam, which is as wide as human body. The height of the beam is small such that the image reconstructed in one resolution represents a small slice of the area of the interest. In order to cover a whole bone or an organ, a stack of images are obtained. This stack of images provide good description of the bone compared to the conventional radiographic image.

Manufacturing bone grafts using a discreet set of 2D image slices acquired using CT is challenging due to its incompleteness. Further, these manufactured bone grafts must adhere to the standards such as biocompatibility and strength sustainability. Hence, the 3D visualization of medical images has been indispensable in the present radiological procedures. Bone grafting is one of the main focuses in medical image processing which also enables realistic visualization and eases off the designing and manufacturing process. Furthermore, the swift designing and testing process shortens the patient's waiting period for the treatment.

The Computer Aided Designing and Computer Aided Manufacturing software systems may be utilized to design and manufacture the bone grafts. Moreover, there are commercial and non-commercial applications to process medical images which may be specific to the needs of the particular medical imaging equipment. Therefore, these software have limited usage in designing and manufacturing of bone grafts. Further, these software solutions may need high computational power. Hence, the intention of this research is to develop a method to reconstruct a complete three dimensional profile of the bone, and thereby facilitate the fabrication and manufacturing of bone grafts. These bone grafts may then tested for mechanical properties such as strength and life span and to reduce post-surgery complications. The manufacturers of bone grafts use prototype molds in fabrication. This pre-fabricated graft may not be compatible with the cavity of the bone. Therefore, this work is focused on providing a comprehensive profile of the interested bones and a software system that provides a visual environment. Further, freely available tools were used to develop this method and the software solution.

2. MATERIALS AND METHODS

2.1 Image acquisition

The internationally recognized standard for acquiring, viewing, storing and distribution of medical images is Digital Imaging and Communications in Medicine (DICOM). DICOM files are usually produced in a sequence. A sequence number is assigned to the corresponding file. A DICOM image includes patient's information such as patient's identification number, name, gender and imaging information such as positioning, and contrast media used. In CT, a stack of 2D image slices are produced. The number of images acquired, varies depending on the anatomical region being scanned and the gap between adjacent slices. Greater sampling provides detailed diagnostic information. In this approach, the acquired DICOM images were processed through a series of steps (Figure 1) to enhance the image quality and to reduce the computational power needed [1].

2.2 Selecting the region of interest (ROI)

The radiographer may acquire images beyond the required region to be examined. The CT images require a large storage capacities. However, to reconstruct a 3D image, all these images are not necessary. Hence, as the first step, the images of the region of interest (ROI) were selected. The application allows the user to scan through the stack of images. Hence, the user may remove the offset slices considering the ROI while retaining the image slices of hosting bones where applicable. This step reduces the processing time and memory required, thereby increase the efficiency of the application.

2.3 Noise / Artifact filter

Artifacts such as noise, simulation and motion hinders the resolution of an image. Noise artifacts are the interrupted signal that may result from the scattered radiation. Further, as the acquisition period for CT is relatively longer, the patient may tend to move during the process leading to motion artifacts producing blurred, disturbed images. The motion artifacts were removed calculating the center of mass in each slice (Figure 3).

2.3.1 Identification and removal of slides with motion artifacts

Shifting image slices may occur in X axis, Y axis or in the both axes. Therefore, these slides should be identified and replaced with the previous slice from the image stack fact that removing identified slices causes incorrect measurements.

2.3.2 Shift detection : Identification of moved slices

A multivariate quality control chart method was used to filter out defective slices. The centroids of the cavity of each slice were captured while isolating the cavity. The X and Y coordinates of the centroid are the two quality characteristics used in the quality control chart model. The T^2 chart [2, 3] for one step (individual observations) process is defined as

$$T^2 = (x - \bar{x})' S^{-1} (x - \bar{x})$$

where, S is defined as

$$S = \frac{1}{m-1} \sum_{i=1}^{m} (v_i - \bar{x})\,(x_i - \bar{x})'$$

for $v_i = x_{i+1} - x_i \quad ; i = 1, 2, \dots m - 1$

the values vi's are arranged in a matrix as

$$V = \begin{bmatrix} v_1' \\ v_2' \\ \cdot \\ \cdot \\ \cdot \\ v_{m-1}' \end{bmatrix}$$

The phase I limits are based on a beta distribution (cite) and they are defined as

$$UCL = \frac{(m-1)^2}{m} \beta_{\alpha, p/2, (m-p-1)/2}$$
$$LCL = 0$$

where $\beta_{\alpha, p/2, (m-p-1)/2}$ is the upper α percentage point of a beta distribution with parameters $p/2$ and $(m - p - 1)/2$.

Figure 2 shows shift verification test for 157 image slices. It is evident that the slices 116, 117 and 118 have shifted significantly. Therefore, they are removed from the image stack before proceeding to the next step.

2.4 Intensity related filters

The optimal intensity for an image is needed to be selected such that the important features are not diminished. In medical image processing, detecting objects by image segmentation is often an arduous process. A fully automated system may generate faulty results when trying to adjust the intensity. Thus the bone graft fabricated may not perfectly be suited the patient. In order to reduce the computer system resources for the contrast adjustment process, the stack of images was converted to the 8-bit gray scale or binary. Figure 4 shows the cavity profile view with different transparency settings.

2.5 3D modeling

The selected and processed 2D digitized images were transformed to a single rectified 3D image using the Marching Cube Algorithm [4].

2.5.1 3D rendering with Marching Cube algorithm

This algorithm extracts the eight neighboring locations when passing through the images and determine a polygon to represent a iso-surface. The polygon treats each of the eight

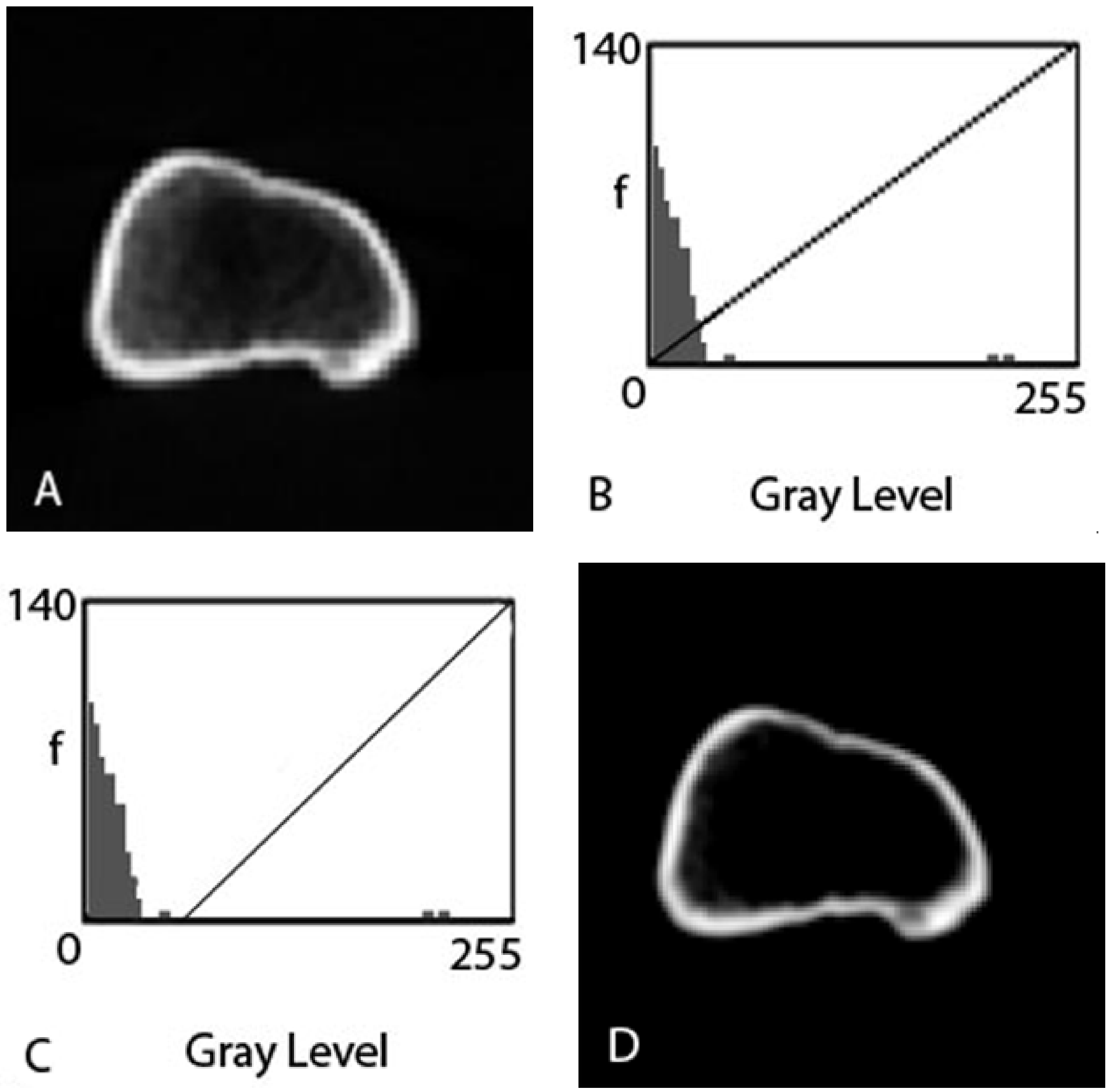

Figure 1: (A) Original slice, (B) Histogram, (C) Triangle method process, (D) Outcome after applying the Triangle method result

scalars as an 8-bit integer. A value is assigned such that it is inside the surface if the scalar value is higher than the iso-value and vice-versa. 15 unique cube configurations or patterns of polygons are generated by the Marching Cubes algorithm [4]. This leads to a wire frame model, thus it is possible to apply shading, look up tables and polygon clipping.

2.5.2 3D rendering with Marching Cube Algorithm

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2.5.3 3D data compression (mesh reduction)

When the lesion area is larger, the amount of polygonal data being generated is also larger. In order to process a large amount of polygonal data, high computational power is needed. Polygon reduction is indispensable as the number of slices are increased in the subjected area. The progressive mesh method [7, 8] was used to reduce the number of triangles in the 3D mesh without effecting the topology. However, the operator is allowed to specify the level of compression that is the amount of triangle meshes. The polygonal data was compressed without changing the topology of the 3D image [9].

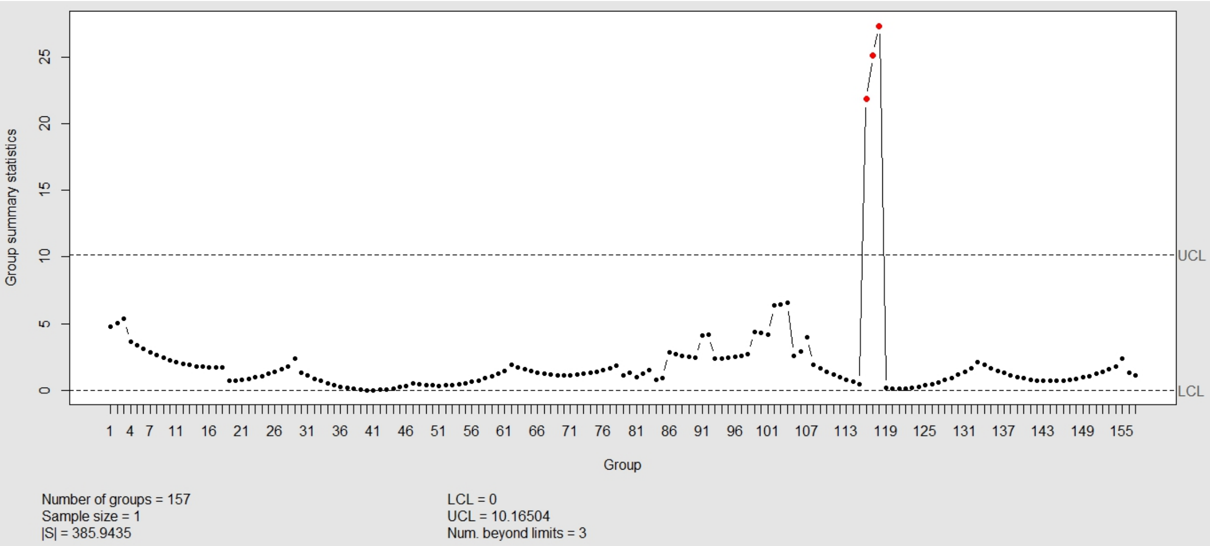

Figure 2: Finding the defect slices using Quality Control Chart (QCC) technique

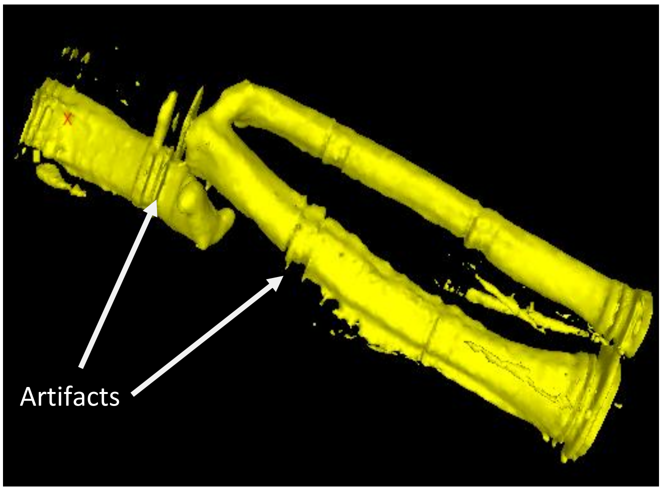

Figure 3: 3D modeling without removing shifted slices

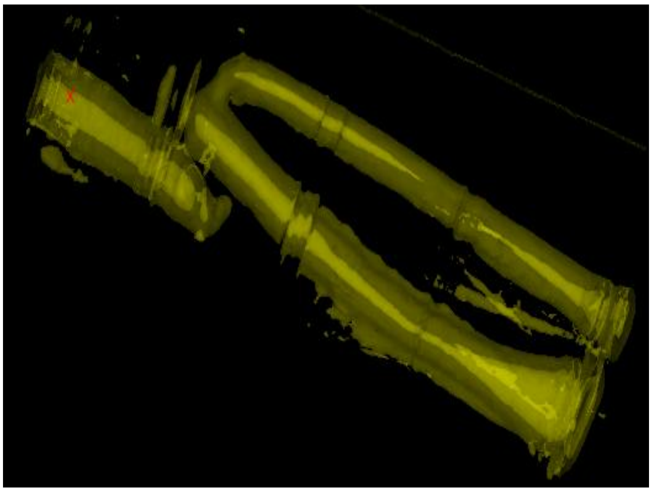

Figure 4: Cavity profile view with transparency variation

3. RESULTS AND DISCUSSION

Extracting and isolating cavity are the main features in the bone substitute manufacturing pipeline as the substitute is insert to cavity [10]. The software developed includes two techniques to isolate the cavity profile as shown in the Figure 4 and Figure 5. However, software coupled to the medical imaging equipments are not equipped with such features.

The developed method and software tool to guide the manufacturing process of bone grafts is exceptional in many aspects. This provides a substantial tool to exclude image slides with motion artifacts. Further, the software tool facilitates to view the cavity independently (Figure 8) and clip the 3D image in any angle in the X,Y,Z coordinates. Hence, as illustrated in the Figure 8 it is straightforward to make any required measurements of the cavity. Furthermore, the developed software tool provides an interface between the model bone graft and the cavity. Therefore, it is possible to ensure the compatibility and even to trial the surgical process in advance of the real surgery (Figure 5). The patients as well as the physicians will be exceedingly benefited by this due to the shorter waiting times and ease of validation process.

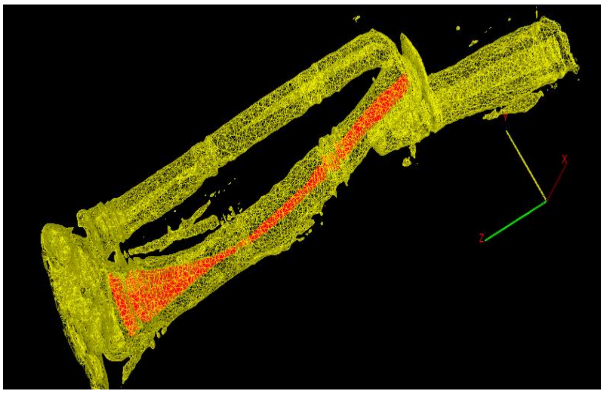

Figure 5: Isolation of the cavity profile

The end user software provided and the interface are equipped with very own characteristics to facilitate the designing, manufacturing and validating process. It is possible to rotate and look at the reconstructed image in all three axes, X,Y,Z in any angle as shown in the Figure 6.

Figure 6 : 3D object Representation: Shaded object with a color look up table

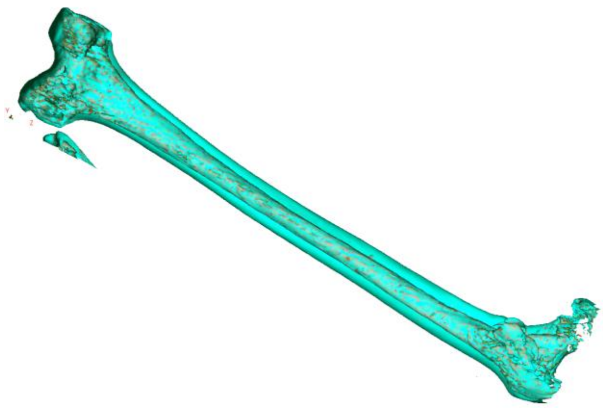

Figure 7: Object observation: Cavity (internal) section view mode

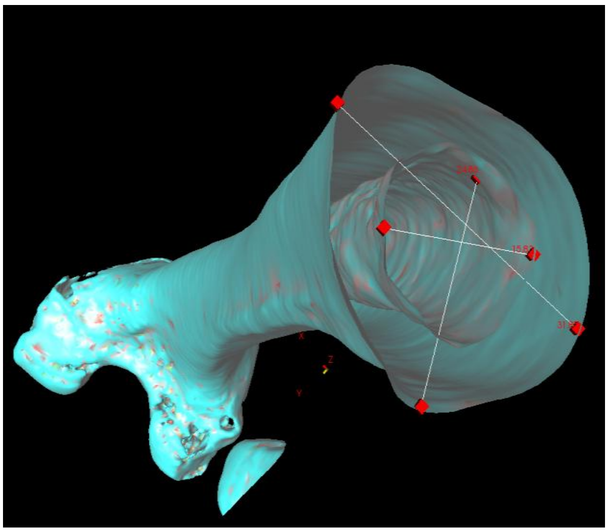

Figure 8: Distance measurements for bone graft manufacturing

Images shown above and results were processed using a low end personal computer at the current market of 8 GB of RAM, 4 GB of VGA and Intel Core i7 processor which operates with a Windows 7 Home Premium 64-bit operating system.

4. CONCLUSION

The artificial bone substitute manufacturing process will be fast and reliable when using the developed approach. Although there are many work performed of this nature only a few complies with advanced user needs. Further, the software shipped with the equipments are not comprehensive. This research work is initiated to account for such deficiencies. The software solution is being designed utilizing mathematical and statistical models and coded using open source software tools. The 2D CT image slices are filtered for quality and then transformed to a single 3D image using the marching cube algorithm. A very user friendly environment is provided. This environment may be used to adjust colors, view and clip the bone in any plane. Further, a 2D profile is made accessible to user in any plane, most importantly in the planes where CT images are not acquired. The software provides the flexibility to import and export files to CAD software. The solution is light weight yet comprehensive hence, may be used even in a personal computer to perform the whole process of designing through the validation of the bone graft.

5. ACKNOWLEDGMENTS

National Research Council (NRC) of Sri Lanka [Grant number: 11-046].

6. REFERENCES

[1] Burger W., Burge M. J., Principles of Digital Image Processing Fundamental Techniques, Springer Publishing Company, 2009.

[2] Hotelling, H., (1947), “Multivariate Quality Control Illustrated by Air Testing of Sample Bombsights”, C.Eisenhart et. al. pp.111-184.

[3] Montgomery, D. C., (1996), Introduction to Statistical Quality Control, Third Edition, John Wiley : Sons

[4] Lorensen W.E., Cline H.E., Marching cubes: a high resolution 3D surface construction algorithm, Computer Graphics, 21(4):163~169, 1987.

[5] Sandip A., Anshul P.,Kapil K., Nirmal P., Ravi B., Total Knee Prosthesis: Design, Manufacture, and Testing, TeamTech 2007.

[6] Ghiba M. O., Rusu L., Geometrical design of custom-made femoral stem prostheses, Fascicle of Management and Technological Engineering, Volume VII (XVII), 2008.

[7] Hoppe H., Progressive Meshes. Conference Proceedings of SIGGRAPH 1996, pp. 99-108.

[8] Schroeder W. J., Zarge J. A., Lorensen W. E., Decimation of Triangle Meshes. Conference Proceedings of SIGGRAPH 1992, pp. 65-70.

[9] Sun W., B. Starly, J. Nam, A. Darling, Bio-CAD modeling and its applications in computer-aided tissue engineering, Computer-Aided Design 37 (2005) 1097–1114.

[10] Jef Vanderoost, G Harry van Lenthe, From histology to micro-CT: Measuring and modeling resorption cavities and their relation to bone competence, World J Radiol. 2014 Sep 28; 6(9): 643–656.