Proceedings of Symposium on Ultrasonic Electronics, Vol. 36 (2015)
5-7 November, 2015

Fabrication of Cancellous Bone Models by a 3D Printer and the Measurement of Ultrasonic Transmission Properties

3D プリンタによる海綿骨モデルの作製と超音波透過特性測定

Masahiro Ohno, Masashi Shoji, Yasuaki Takahashi, and Takafumi Fujii
(Chiba Institute of Technology)
大野正弘，正司誠司，高橋康明，藤井隆文（千葉工大）

1. Introduction

Three-dimensional (3D) technologies have been greatly incorporated into medical sciences. Among them, application of 3D printing is now gathering attention of doctors and engineers. To date, applications such as making models for medical education, surgery rehearsal with 3D models, and making personalized artificial bones have been reported[1,2]. The idea of making 3D bone models has already been proposed, but decent models are not yet available. If we can make good bone models (bone phantoms) with various structures, for instance, models imitating healthy bones as well as diseased bones at various degrees in osteoporosis, a great merit will be expected in developing and calibrating instruments and in training technicians. In this paper, we report our attempt to make bone models by a 3D printer. Our present interest is in making cancellous bone models the parameters of which can be independently controllable. Cancellous bones have plural structural parameters, such as mean pore diameter, mean trabecular thickness, and anisotropy factors. When we use natural human or animal bones for the measurement of ultrasonic propagation properties, we cannot expect to change such parameters independently. The use of 3D designing and printing techniques, however, may make it possible to change parameters independently. In the following, we report our attempt to make cancellous bone models that have the same network structure but different trabecular thicknesses.

2. Method of Making Models

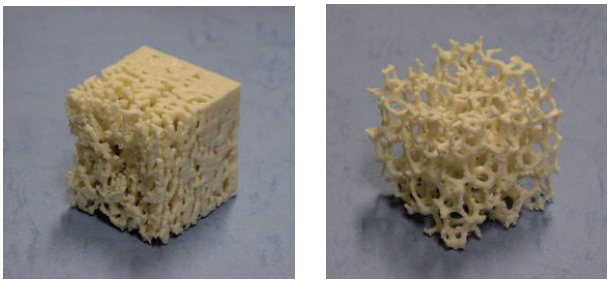
We have made cancellous bone models by the following method.

(1) Obtain X-ray CT images of natural or artificial porous materials such as bovine bones or artificial sponge: A set of X-ray CT images for a model consists of 512 two-dimensional images scanned at an interval of 72 μm. These images were stored as DICOM files. (2) Convert DICOM image files to three-dimensional volume data: A software package *Volume Extractor* (i-Plants Systems) was used for this purpose. (3) Convert volume data to polygon data: In *Volume Extractor*, an arbitrary threshold value can be allocated to a volume data to define the location of the surface of a polygon to make. Since the initial X-ray CT images have a finite resolution, the location of the surface of a polygon can be shifted by changing the threshold value. This means that we can convert one volume data to various polygons that have different surface positions. By using this function, we made many cancellous bone models that have the same network structure but different trabecular thicknesses. The resultant polygon data were stored as STL files. (4) Print STL polygon data by a 3D printer: We used a 3D printer *Cube* (3D-Systems), which uses fused deposition modeling method with ABS (acrylonitrile butadiene styrene) as material. Some preliminary processings such as healing (data optimization), scale conversion, and selection of printing direction are available.

ohno.masahiro@p.chibakoudai.jp

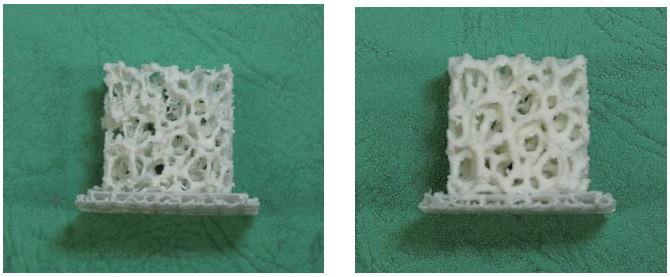
3. Results of 3D Printing

First, we tried to print the polygons at the same size (100% scale) as the initial models. However, neither the bovine bone nor the sponge were printed out successfully, presumably because some trabeculae in the polygons were thinner than the resolution of the printer, 200μm. Sometimes trabeculae thicker than this could not be printed due to the mechanical unstableness of the thin resin in the printing process. Therefore, we tried to print enlarged models. The polygon data were enlarged by 300% in the above process (4). Since the whole volume was too big to be printed out by *Cube* at this scale, trimmed models were printed out. **Fig.1**(a) shows a printed model made from a bovine bone, whereas Fig. 1(b) shows one made from a sponge. The model from a bovine bone consists of thick and thin trabeculae, the latter of which were sometimes difficult to print. Trabeculae of the model made from a sponge had rather uniform thickness, which was suitable to control by thresholding. Therefore, we decided to make models for the following experiment from the sponge data.



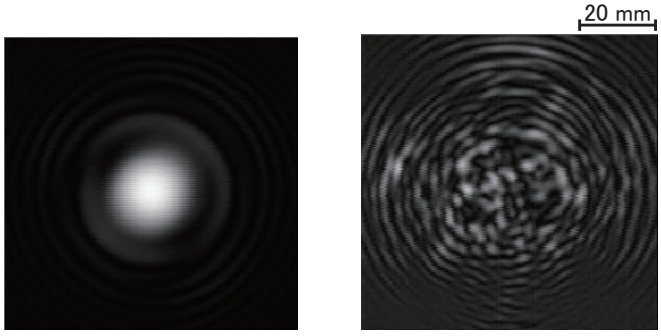
(a) made from a bovine bone (b) made from a sponge

Fig. 1 Printed bone models.



(a) w=2.18 g (b) w=4.10 g

Fig. 2 Models having different trabeculae thicknesses



(a) Field in free space (b) Field transmitted from the model of Fig 2(b)

Fig. 3 Ultrasonic field distributions.

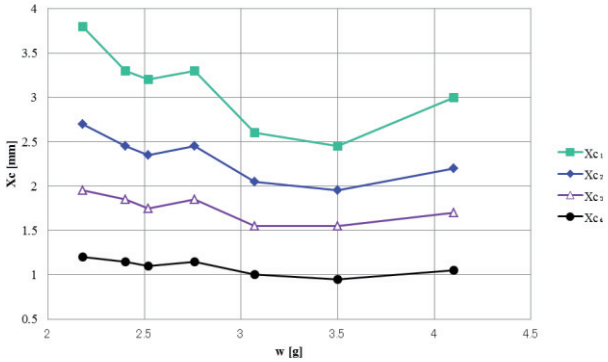


Fig.4 Autocorrelation width Xc as a function of the weight of models.

4. Experiment of Ultrasonic Scattering

We have performed an experiment of ultrasonic scattering using bone models made by above-mentioned method. The purpose of this experiment is to compare the fields of ultrasound transmitted through bone models that have the same network structures but different trabecular thicknesses. To do this, we made seven models from one sponge volume data with seven different threshold values. **Fig. 2** shows two of them. The value w shows the weight of each model, which can be used as a parameter corresponding the remaining bone amount in osteoporosis. Experiment was performed as follows. Tone-burst ultrasonic waves at 1 MHz, duration of 10 μs, were radiated from a plane circular transducer the diameter of which was 12 mm. The field distributions after passing through bone models were visualized by scanning a needle-sized (active area 0.5 mmϕ) hydrophone two-dimensionally. **Fig. 3** shows the obtained ultrasonic fields. These images were constructed from the values of envelope-detected amplitudes of ultrasound, but not from instant AC values. To evaluate the degree of scattered field's complexity, we calculated two-dimensional autocorrelation function of each image[3]. Since the autocorrelation function becomes peaky for fast varying signals, the width of the autocorrelation curve around its peak can be used as an index of the complexity. **Fig. 4** shows the values Xc, the separation of two points where autocorrelation value becomes 20%(X_{c1}), 15%(X_{c2}), 10%(X_{c3}), and 5%(X_{c4}) smaller than its peak. The value Xc generally decreases for larger weight, which coincides with our expectation that the larger amount of cancellous bone, provided that the network has the same structure, would generate more complexed scattering fields. However, the values for w=4.1 g cannot be well explained.

5. Summary

We have made cancellous bone models by processing X-ray CT data of natural bones or artificial porous materials and printing them by a 3D printer. Trabecular thickness could be changed by controlling the threshold value in constructing polygon data. Ultrasonic scattering experiment was performed for models, which confirmed more complexed scattering occurs for thicker trabeculae. Future work may include making models at the original (100%) scale, making cortical bone part, evaluating the elastic properties of the plastic used for 3D printing.

References

1. P. Giacomelli and A. Smedberg: *The Sixth Int'l Conference on eHealth, Telemedicine, and Social Medicines*, (2014) 49.
2. I. Kroonenburgh *et. al.*: Digital Dental News, **6** (2012) 60.
3. M. Ohno, T. Nagaishi and A. Iwabuchi: *Proc. Symp. Ultrasonic Electronics*, **33** (2012) 45.