Bone Structure Radiological Image Analysis of Healthy People and People with Osteoporosis

M. Kovalovs*, A. Glazs

Image Processing and Computer Graphics Department,
Riga Technical University, Latvia
E-mail: mihails.kovalovs@rtu.lv

Introduction. Bone structure radiological image analysis is necessary, when determining the bone strength and measuring the bone micro architecture deterioration, that happens as a result of such a bone disease as osteoporosis. Medical images that were acquired by computed tomography are divided into slices. Traditionally, medical images analysis is performed by a radiologist, who visually looks through all of the two-dimensional images. Such analysis is subjective and takes a considerable amount of time. To speed up the analysis and acquire reproducible measurements, it is necessary to use automatic medical image processing methods.

In recent years there has been an increased interest in developing techniques to analyse medical images to evaluate bone microstructure [1]. Most of these techniques are manual or semi-automatic algorithms and use medical images, that were acquired by high resolution computed tomography and magnetic resonance imaging tools [2] that are fairly expensive and not available in most clinics. The methods that are proposed in this paper were developed using the images that were acquired using computed tomography, because medical images that are acquired by using this method, are widely used in clinical practice when diagnosing patients.

The proposed method was described in detail in previous publications [3], it was also tested on medical images of people with osteoporosis, to see whether it could be used to evaluate the changes in bone structure [4]. In this paper the proposed method was tested on medical images from two patient groups – healthy people and people with osteoporosis. The main goal was to see whether the proposed method is capable of extracting the bone structure from the medical images of both patient groups and to analyse the cortical bone thickness and trabecular bone density measurements from both patient groups.

Proposed method. One of the main objectives was to develop a fully automatic algorithm that does not require input from the user. This is necessary in order to ease and speed up the job of the doctor, who will be working with the medical images. However, the user still has the option to change the main parameters of the algorithm, in order to increase the precision of the segmentation algorithm for a specific patient. The proposed algorithm mainly consists of eight steps:

1. A medical image (Fig. 1a) is divided into segments, which could contain the cortical bone (Fig. 1b).
2. Segments, that were created in the last step, are combined into clusters

3. Clusters are classified, in order to find those clusters that contain the cortical bone and discard all other clusters (Fig. 1c).
4. An inner contour is created inside the previously extracted cortical bone that adapts to the inner edges of the cortical bone.
5. Trabecular bone is extracted from the inside of the previously created contour (Fig. 1d).
6. An outer contour is created, which is initially based on the inner contour, but then expands and adapts to the outer edges of the cortical bone.
7. The thickness of the cortical bone is measured as an average distance between the control points of the inner and outer contours (Fig. 1e).
8. The average density of the trabecular bone is measured as a ratio between the pixels that belong to the trabecular bone and all other pixels inside a fixed region at the center of the trabecular bone (Fig. 1f).

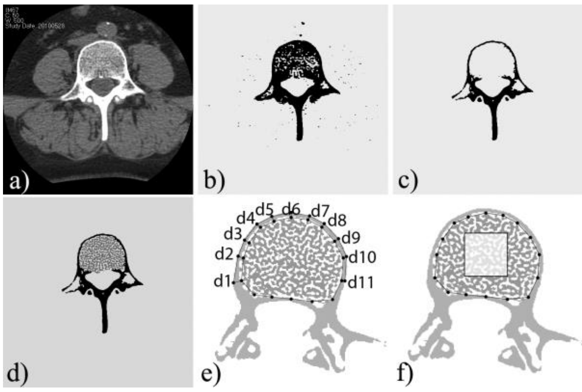

Fig. 1. Cortical bone extraction from medical images of a human vertebra

All steps are executed automatically without interruptions for user input. The first three steps apply to the extraction of the cortical bone and they produce an image with an extracted cortical bone (Fig. 1c). The next two steps apply to the extraction of the trabecular bone and they produce an image with both the extracted cortical bone and the trabecular bone in different colours (Fig. 1d). The last three steps are the bone structure analysis that produce the bone structure measurements (Fig. 1e and Fig. 1f).

The main goal of bone structure analysis is to measure the changes in bone structure over a period of time. This is useful for patients with osteoporosis, whose bone structure deteriorates over time and it is necessary to determine the rate of deterioration and evaluate the effectiveness of treatment. Two bone structure parameters are measured: average thickness of the cortical bone and average density of the trabecular bone.

The average thickness of the cortical bone is measured as an average distance between the control points of the inner and outer contours (fig. 1e). In the case of medical images of the vertebra, it is only necessary to measure the upper part of the cortical bone. That is done because the bottom part of the vertebra's cortical bone contains projections (spinous and transverse process). These projections would significantly affect the average thickness measurements, because their shape and size varies across all the medical images of a single vertebra.

The trabecular bone density is measured as a ratio between the image pixels that belong to the extracted trabecular bone and all other pixels that are located inside a fixed region at the center of to the trabecular bone. To get more accurate measurements of trabecular bone density, only a small region of the trabecular bone is analysed and the size of this region does not change between multiple different images (Fig. 1f).

Experiment. Experiments have been conducted with the proposed method. It was used to extract the cortical and trabecular bone from the medical images and measure bone thickness and density. The algorithm was tested on sets of medical images from two patient groups. The first group consisted of eight practically healthy (not diagnosed with osteoporosis) patients aged 18 to 26 years, these patients underwent examination of the lumbar spine due to spondylosis or disc disease. The second group consisted of six patients, diagnosed with osteoporosis, aged 55 to 86 years. The model of the CT scanner, which was used in the experiment, was: GE Brightspeed 16, with the following settings:

- Anode current: 380 mA, 120 kV;
- Slice thickness: 2.5 mm;
- Scanning step: 2.5 mm;
- Reconstruction image: Bone window 2.5 and Standard window 1.25;
- Field of view: 16 cm

In radiology, bone structure analysis usually focuses on the fourth (L4) and fifth (L5) vertebra of the lumbar spine. Therefore, the experiments were focused on one specific vertebra – the L4 vertebrae. The medical images of the L4 vertebrae of one patient can contain from 9 up to 15 medical images.

Table 1. Bone structure measurements of practically healthy patients

Patient number	Age (years)	Cortical bone average thickness (pixels)	Trabecular bone average density (ratio)
1	25	4.333	1.763
2	26	7.566	1.733
3	18	4.252	1.832
4	19	9.059	1.696
5	22	7.344	1.406
6	21	14.684	1.226
7	24	30.572	1.889
8	23	6.172	2.082
Average		7.630	1.677

The Table 1 shows the bone structure measurements of eight practically healthy (not diagnosed with osteoporosis) patients. The developed bone structure extraction and analysis algorithms have successfully managed to extract the bone structure and measure the cortical bone thickness and the trabecular bone density from the medical images of almost all eight practically healthy patients. The only exception where the developed algorithms have failed are the medical images of the 7th patient. This patient had a very high bone density and the chosen cortical bone density threshold was too small, because of that the developed algorithm incorrectly extracted cortical bone from the medical image, which significantly increased the thickness measurement.

It was decided to exclude the measurements of the 7th patient from the average measurements of all patients. Otherwise to correctly extract the bone structure of the 7th patient, it would be necessary to increase the cortical bone threshold value, but then it would be difficult to extract the bone structure from patients with osteoporosis, whose bone density is low.

Table 2. Bone structure measurements of patients diagnosed with osteoporosis

Patient number	Age (years)	Cortical bone average thickness (pixels)	Trabecular bone average density (ratio)
1	56	5.306	1.610
2	55	1.936	1.455
3	79	2.431	1.764
4	83	1.317	1.618
5	75	1.474	1.339
6	56	2.460	1.837
Average		2.487	1.604

The Table 2 shows the cortical bone average thickness and trabecular bone average density measurements of six patients with osteoporosis. The measurement results of all patients were roughly similar, with only one exception. The cortical bone average thickness of the 1st patient was significantly greater than other patients, because this patient had a tumour on the cortical bone. Based on the results of the experiment, it can be concluded, that the developed bone structure extraction algorithm is able to successfully extract the cortical and trabecular bone from both the healthy patients and patients with osteoporosis.

Conclusions. By comparing the tables 1 and 2, it can be seen that the cortical bone average thickness measurements in practically healthy patients are significantly higher (almost 4 times higher), than in patients with osteoporosis. Although the trabecular bone average density measurements are approximately the same for both patient groups. Based on the results of the experiment it can be concluded, that it is possible to distinguish the healthy patients from patients with osteoporosis on the basis of their cortical bone thickness measurements, which are produced by the developed bone structure analysis algorithms.

The results of the experiments have shown that the developed methods can extract and measure the cortical bone average thickness and the trabecular bone average density from both the healthy patients and patients with osteoporosis. In previous publications it was shown that the changes in bone structure can be evaluated by comparing the measurements that were performed on medical images of people with osteoporosis that were taken at various time intervals [3]. The developed bone structure analysis methods, would be useful, when treating patients with osteoporosis, where by analysing the changes in bone structure, it would be possible to evaluate the effectiveness of the treatment plan of osteoporosis.

References

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Bone structure analysis is necessary, when determining the bone strength and measuring the bone micro architecture deterioration, that happens as a result of such a bone disease as osteoporosis. In this paper a method is proposed to automatically measure changes in bone structure by analysing medical images, which were acquired by computer tomography at different time intervals. The proposed method was tested on sets of medical images from two patient groups: practically healthy patients (not diagnosed with osteoporosis) and patients diagnosed with osteoporosis.