Automatic Medical Image Analysis for Measuring Bone Thickness and Density

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Introduction. Bone structure analysis is necessary, when determining the bone strength and measuring the bone micro architecture deterioration, that happens as a result of such bone disease as osteoporosis. Bone structure analysis on a living person (*in vivo*) is easier and more effective to perform by using medical images. Traditionally, medical images analysis is performed by a radiologist, who visually looks through all of the two-dimensional images that are divided into slices. Such analysis is subjective and takes a considerable amount of time. To speed up the analysis and acquire reproducible measurements, it is possible to use a computer and automatic medical image processing methods.

Several methods are available to measure bone density, but currently the most widely used technique is DEXA (Dual Energy Xray Absorptiometry), which provides areal bone mineral density (BMD). But recently it has been found that BMD is a limited predictor of fracture risk and that the bone's architectural make-up significantly contributes to bone strength [1]. So it is also necessary to analyze the bone microstructure using medical images, which are acquired by computer tomography or magnetic resonance.

To analyze the medical images, first it is necessary to define the region of interest (ROI), which in this case is the cortical bone and the trabecular bone. ROI can be defined manually by a trained operator, but there are also many algorithms that can do such task, but they are mostly semiautomatic, which means that at some point the operator must define a rough manual outline of the ROI or manually adjust the ROI created by the algorithm [2].

In this paper a method is proposed that measures cortical bone thickness and trabecular bone density. This method automatically defines the cortical and trabecular bone ROI on medical images that were acquired by computed tomography. This method was mainly intended to measure the effectiveness of treatment of osteoporosis, by analyzing several sets of medical images, taken at time intervals to measure the changes in cortical and trabecular bone.

Proposed method. Before it is possible to measure the cortical bone thickness and the trabecular bone density, it is first necessary to perform the medical image segmentation, where the soft tissue is removed from the medical image. The medical image segmentation is done based on the radiodensity of each pixel in an image. The Hounsfield scale is used to define a radiodensity threshold of a cortical bone and all the pixels, whose radiodensity falls outside the defined threshold are blackened, which leaves only the cortical bone on the medical image.

Next it is necessary to group pixels into clusters and find the cluster that contains the cortical bone and remove all other clusters. Because osteoporosis causes bone degradation, the cortical bone may consist of several clusters so the simple thresholding used before, is not sufficient to extract the cortical bone. Thus it is necessary to expand the threshold, so that the image would also contain the tissue, whose density is close to that of a cortical bone, thus extracting a larger region (Fig. 1b). Then the pixels are grouped into clusters and threshold is decreased to an appropriate value, removing all of the corresponding pixels, while maintaining the clusters (Fig. 1c). Finally the cluster that contains the cortical bone is found, which is usually the largest, and all other clusters are removed (Fig. 1d)

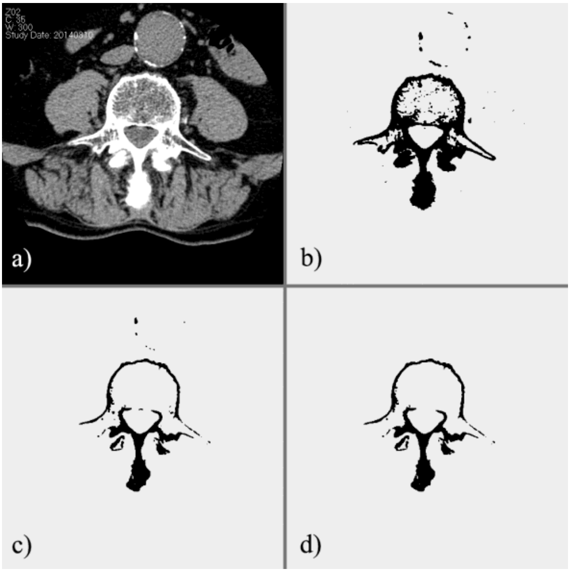

Fig. 1. Segmentation of an image of spine

The second step is extracting the trabecular bone from the medical image. This is done by creating a contour that adapts to the inner edge of the cortical bone.

To create this contour it is first necessary to find a center point of the cortical bone. After the center point has been found the first four points of the adaptive contour are placed at this center point. Each point is assigned a movement vector with the opposite directions (Fig. 2a). Then each point of the contour starts moving in the direction of its vector, one pixel at a time. If a distance between any two neighboring points of the contour surpasses a set distance (10 pixels), then a new point is created between these points (Fig. 2b).

When a point reaches the cortical bone it stops moving, the algorithm stops when all of the points stop moving (Fig. 2c).

The final step is the extraction of the trabecular bone from inside of the previously created contour. The inverse Laplace filter is used to extract the trabecular bone. The Laplace filter is an edge detection filter and here the inverse version is used to highlight the trabecular bone in the image. To extract the trabecular bone from the medical image the inverse Laplace filter is applied to the area inside the previously created contour (Fig. 2d).

To measure the cortical bone thickness a second contour is created, that adapts to the outer edge of the cortical bone. This contour is created by copying the first contour and expanding it (Fig. 2d) until all control points are located on the outer edge of the cortical bone (Fig. 2e). When measuring the average thickness of the cortical bone of the spine, it is only necessary to measure the upper part of the image, where the average thickness of the cortical bone is more or less uniform, so when the outer contour is created, those points with direction vector pointing downward are ignored. The cortical bone average thickness is measured as an average distance between the control points on the inner and outer edges of the cortical bone (Fig. 2f).

In the previous work [3], additional points would also be created on the outer contour, to better describe the shape of the cortical bone. This was useful, when measuring the cortical bone porosity, but such complexity is unnecessary when measuring the cortical bone thickness, so this method does not create any additional points. The algorithm for creating the adaptive contour was also improved since then by implementing an ability to detect and ignore holes in the cortical bone [4].

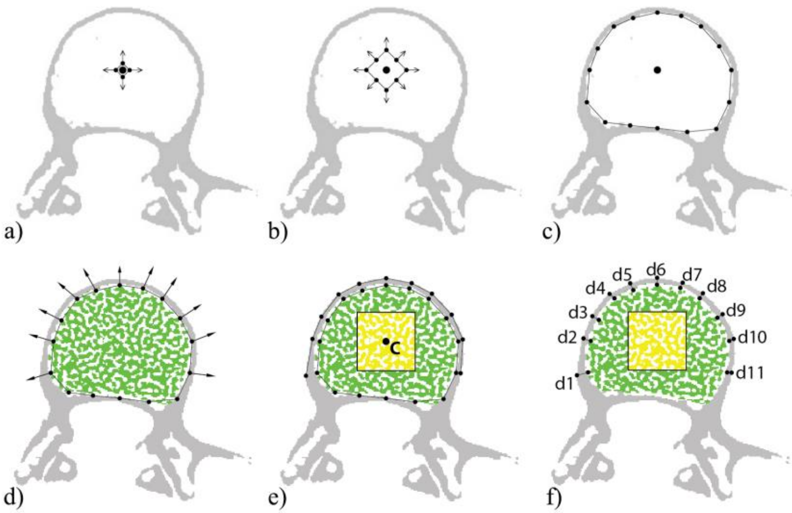

Fig. 2. Creating the cortical bone contours and measuring the cortical bone thickness and trabecular bone density

The trabecular bone density is measured inside a fixed rectangular region, which is created around the center point of the inner contour. The size of the region is chosen, so that it would cover the largest area, while still fitting inside the trabecular bone across all the images, that are being analyzed, and the size must remain exactly the same across all the images, so that it would be possible to compare the measurements between the different images.

The trabecular bone density is measured as a ratio between the image pixels that are located inside the fixed region and belong to the trabecular bone (Fig. 2f. in yellow) and those that do not (Fig. 2f. in white).

Experiment. The proposed method was tested on two sets of medical images from nine patients suffering from osteoporosis, with different time periods between each set (from 6 to 46 months), to measure the changes in bone structure of the spine. Each set contained from 9 to 12 medical images (slices) of the L4 spinal segment, that were acquired using conventional computed tomography. The proposed method was used to measure the cortical bone thickness and trabecular bone density on each image from the set, then the average measurements were calculated for the entire set. The difference in thickness and density between the two sets, was also calculated for each patient. The results can be seen in table 1.

Table 1. Average bone thickness and density measurements

Patient Nr.	Time Period	Cortical bone average Thickness (in pixels)			Trabecular bone average density (ratio)		
		Before	After	Difference	Before	After	Difference
1	6 months	4.714	4.561	-3.24%	1.705	1.693	-0.74%
2	11 months	3.330	3.020	-9.31%	1.618	1.608	-0.63%
3	13 months	5.756	5.106	-11.30%	1.802	1.627	-9.72%
4	25 months	2.577	2.394	-7.09%	1.930	1.783	-7.59%
5	25 months	5.647	5.391	-4.53%	1.757	1.480	-15.72%
6	32 months	4.58	3.969	-13.43%	1.732	1.638	-5.42%
7	35 months	2.473	3.687	+32.93%	1.863	1.564	-16.06%
8	35 months	4.109	3.750	-8.72%	1.693	1.532	-9.50%
9	46 months	4.255	3.938	-7.45%	2.194	1.678	-23.53%

The values in table 1 show that bone density and thickness in most patients decreases over time, which is what usually happens with patients with osteoporosis, the only exception is patient Nr. 7, that had an abnormal growth on the spine.

Conclusions. The proposed method was tested on a few hundred medical images, and it proved capable of extracting the cortical and trabecular bones from images and measuring the cortical bone thickness and trabecular bone density. In future works it is planned to test the accuracy and reliability of the proposed method, but it would require data from considerably more patients.

The main advantage of the proposed method is that it is fully automatic, the only time it might need an operator input is if the operator chooses to change the radiodensity threshold that is used to extract the cortical bone.

The proposed method could be used when analyzing the medical images of patients with osteoporosis, where it is necessary to analyze the changes in the microstructure of the bone. This method could also be used in studies, where it is necessary to analyze a large amount of medical images.

References

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Bone thickness and density decreases over time due to aging and such bone diseases as osteoporosis. In this paper a method is proposed to automatically measure changes in bone thickness and density by analyzing medical images, which were acquired by computer tomography at different time intervals. The proposed method automatically extracts the cortical bone and the trabecular bone from medical images and measures the average cortical bone thickness and trabecular bone density across several medical images. This method could also be used in studies, where it is necessary to analyze a large amount of medical images.