Trabecular Bone Segmentation by Using an Adaptive Contour

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Abstract **– This paper proposes a method for extracting a trabecular bone region from medical images of bones, which can be later used for diagnosing patients suffering from osteoporosis. This approach is fully automatic and does not require operator input; it can be used on two types of bones: long bones and vertebrae. The first step is segmenting the medical image, which leaves only the cortical bone, then a contour is created inside the cortical bone, which adapts to the edges of the cortical bone and ignores the holes that could appear in the cortical bone, thus extracting the trabecular bone that is located inside the cortical bone.**

Keywords **– Medical images, segmentation, trabecular bone.**

I. Introduction

There are two major kinds of bones: cortical and trabecular ones (see Fig. 1). The hard outer layer of bones is composed of cortical bone tissue. This tissue gives bones their smooth, white, and solid appearance, and accounts for 80% of the total bone mass of an adult skeleton. Filling the interior of the bone is the trabecular bone tissue (an open cell porous network also called cancellous or spongy bone), which is composed of a network of rod- and plate-like elements that make the overall organ lighter and allow room for blood vessels and marrow. Trabecular bone accounts for the remaining 20% of total bone mass but has nearly ten times the surface area of compact bone. The trabecular bone is usually found at the ends of long bones and inside the vertebra.

Osteoporosis is a bone disease, in which the bones become brittle and fragile from loss of tissue, typically as a result of hormonal changes, or deficiency of calcium or vitamin D. At present, osteoporosis is mostly diagnosed by measuring the bone mineral density (BMD), which is usually obtained using dual-energy x-ray absorptiometry (DXA). DXA is a two-dimensional, projection-based radiographic technique that measures integral BMD of both cortical and trabecular bone. BMD only explains about 70% to 75% of the variance in bone strength [2], while the remaining variance is due to the cumulative and synergistic effect of other factors such as bone architecture, tissue composition and micro damage [3] – [5].

In recent years there has been an increased interest in developing techniques to analyse a medical image to evaluate bone microstructure [6], [7]. Most of these techniques use medical images acquired by high resolution computed tomography [8], [9] and magnetic resonance imaging tools [10], [11] that are fairly expensive and not available in most clinics.

Most of the existing methods of extracting the trabecular bone from medical images are semi-automatic ones, i.e., at a certain point during the medical image analysis an input from the operator is required.

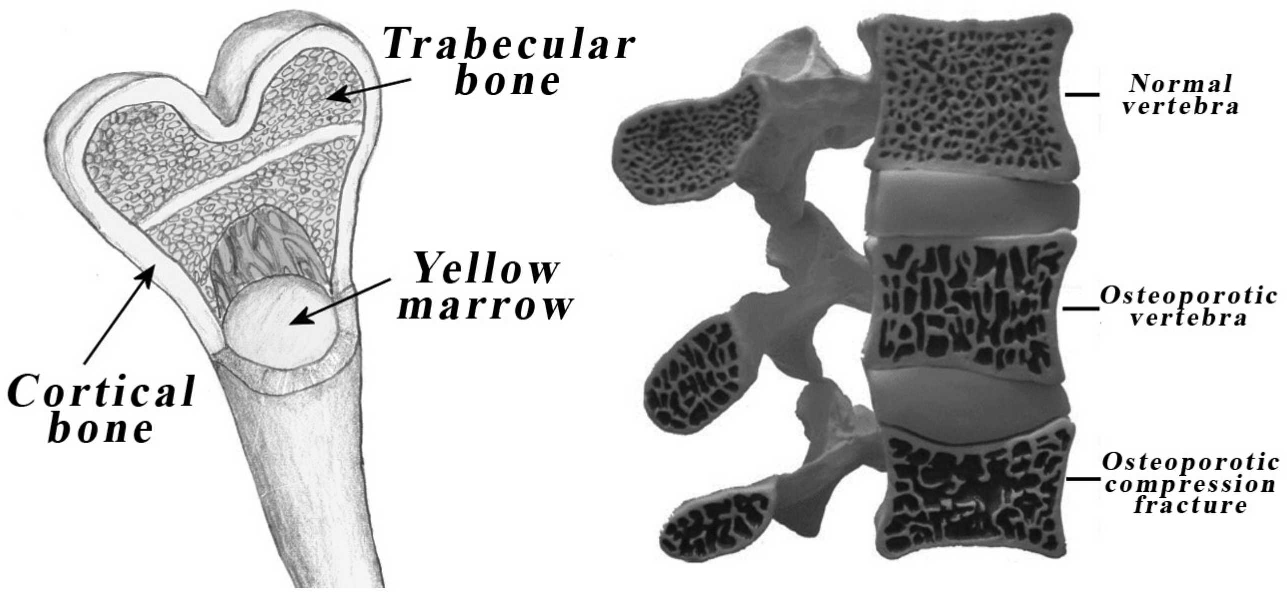

Fig. 1. Long bone showing different bone types on the left, and a human vertebra showing different stages of osteoporosis on the right.

II. The Proposed Method

In this paper, a method of automatic trabecular bone segmentation by using an adaptive contour is proposed. This method uses medical images that were acquired using conventional computed tomography. It automatically finds and defines the trabecular bone region of interest and this method also works in cases, when the cortical bone has holes in it that appear due to cortical bone thinning (see Fig. 2).

The proposed method consists of three steps: medical image segmentation, creating a contour that adapts to the inner edge of the cortical bone, extracting the trabecular bone from inside the created contour.

A. *Medical Image Segmentation.*

The first step in extracting the trabecular bone is the medical image segmentation. In this step the medical image is processed, so that the medical image contains only the cortical bone.

In a medical image, the light intensity of each pixel represents the radiodensity of the matter [12], [13], where the bright pixels represent more dense matter, and darker pixels represent less dense matter. Thus, to extract the cortical bone from the medical image we need to define a radiodensity threshold that corresponds to the radiodensity of the cortical bone, and then all of the pixels that fall outside this threshold are blackened, which leaves only the cortical bone on the image. The radiodensity threshold of the cortical bone can be defined by using the Hounsfield scale [14], which provides a scale of matter based on their radiodensity, where the

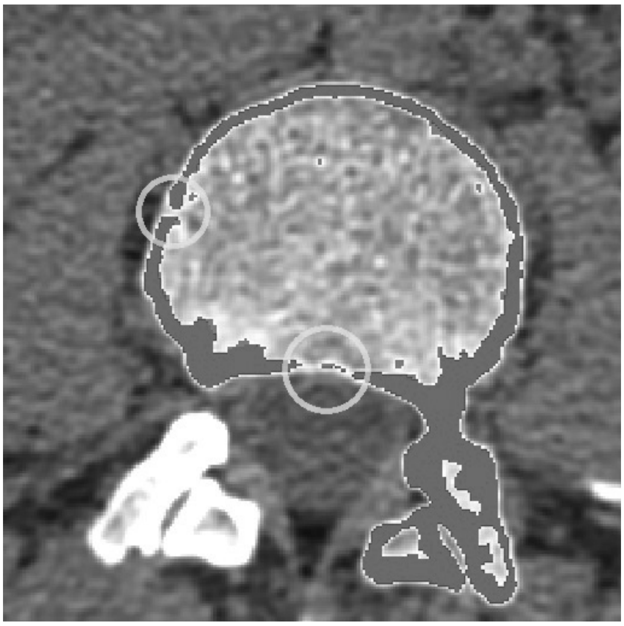

Fig. 2. Medical image of the human vertebra with an extracted cortical bone, the circles show holes in the cortical bone.

radiodensity of air is -1000 HU, water is 0 HU and the radio density of the cortical bone is above 300HU.

When extracting the cortical bone from the medical image by using a radiodensity threshold it is possible that the image still contains pixels that do not belong to the cortical bone, but they have a similar radiodensity; this may be seen in Fig. 3, where the threshold procedure has left some parts of the table on the image. In this case it is necessary

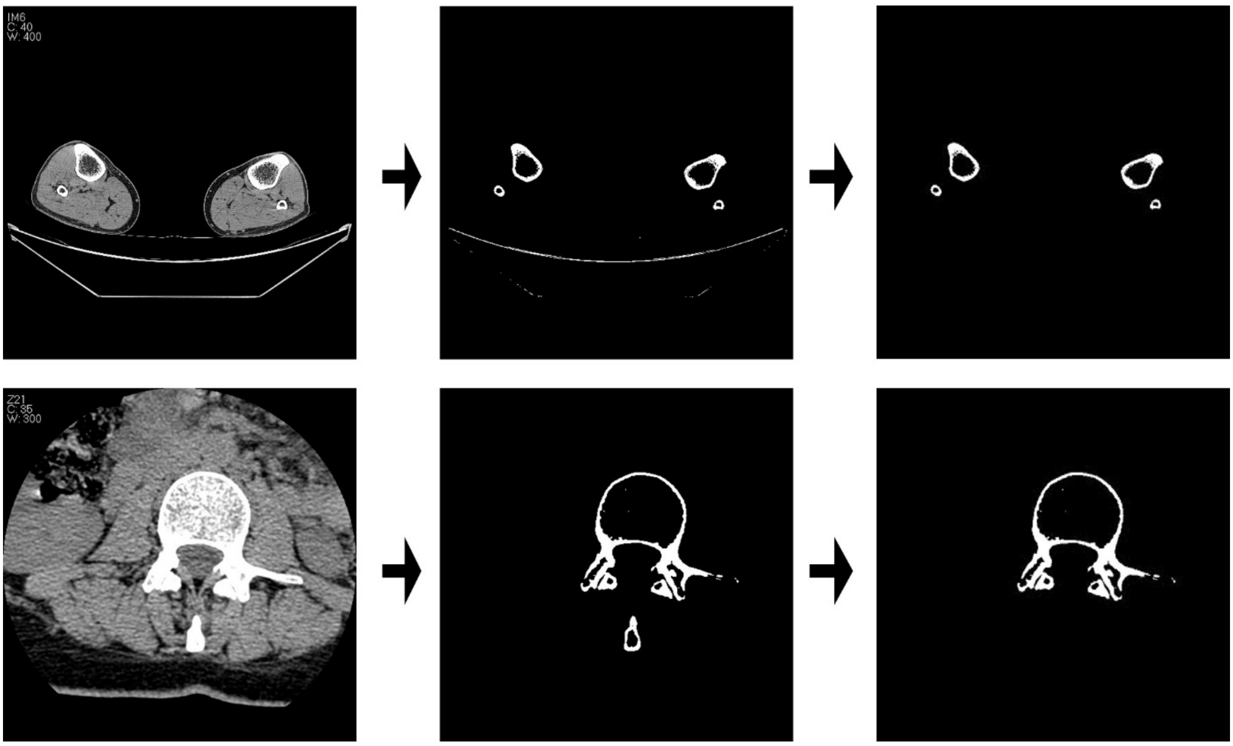

Fig. 3. Medical image segmentation of legs (top row) and vertebra (bottom row), where the left column demonstrates the input medical images, the middle column shows the images with the applied radiodensity threshold, and the right column shows the extracted cortical bones.

to process the image by joining pixels into clusters and classifying these clusters to figure out which of these clusters represent the cortical bone and to remove all other clusters [15]. In the case of the medical images of vertebra, it was only necessary to join pixels into clusters, to find the largest cluster and to remove all other clusters.

B. Creating the Adaptive Contour

The second step in extracting the trabecular bone from the medical image is the creation of a contour that adapts to the inner edge of the cortical bone.

To create this contour it is first necessary to find a centre point of the cortical bone. In the case of long bones, the centre point can be found by looking through all the pixels that belong to the cortical bone and finding the minimum and maximum values on the x and y axis, and the centre point will be right in the middle between the minimal and maximal values (Fig. 4).

The same approach cannot be used with the vertebra, because, by using that approach, the centre point might be outside the cortical bone. Thus, in the case of the vertebra the centre point is found by horizontally scanning the image from the top to bottom and counting how many times each horizontal line intersects the cortical bone (Fig. 4). If the number of intersections equals 4 then a centre point for this line is calculated, which is located in the middle of all the intersections. When the number of the intersections for a line becomes more than 4 then scanning stops and the centre point of the cortical bone is calculated as an average point of all the centre points of the horizontal lines that have four intersections.

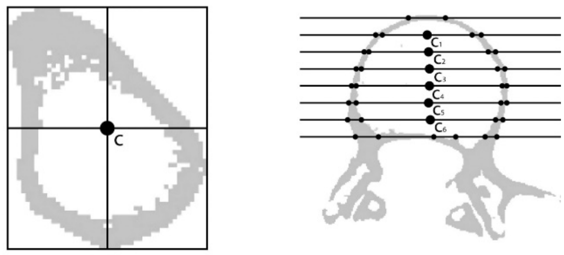

Fig. 4. Finding the centre point of the cortical bone, on the tibia bone (left) and the vertebra (right).

When the centre point is found, the first four points of the adaptive contour are placed at this centre point. Each point is assigned a movement vector with the opposite directions (Fig. 5a). 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 neighbouring points of the contour surpasses a set distance (10 pixels), then a new point is created between these points; the movement vector of this point is calculated as an average vector of the movement vectors of its neighbouring points (Fig. 5b). When a point reaches the cortical bone, it stops moving, the algorithm stops when all the points stop moving (Fig. 5c).

If the cortical bone has holes in it, then a point of the contour might go through it (Fig. 5d), then this point needs to be removed. This is done in the following way. When a point reaches the cortical bone, it stops moving, after that no new points can be created between the given point and its neighbouring points, even if the distance between them surpasses 10 pixels. If the distance between any two neighbouring points surpasses 20 pixels, then the point that is not located on the cortical bone is removed (Fig. 5e).

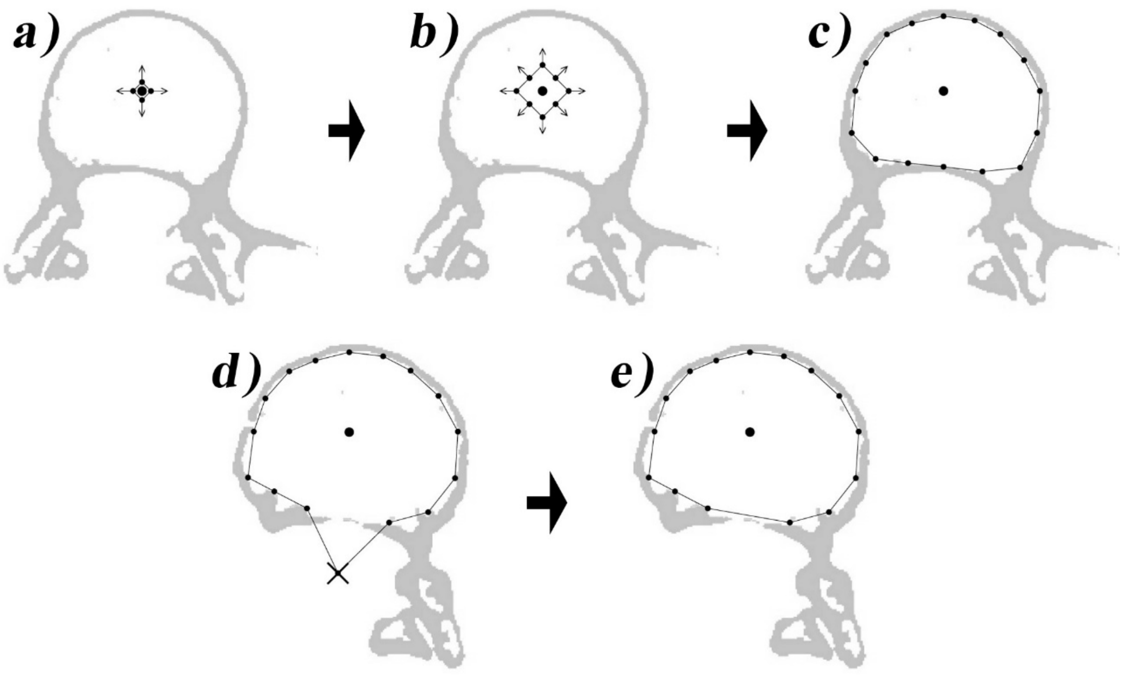

Fig. 5. a, b, c – Creation of the adaptive contour; d, e – ignoring the holes in the cortical bone.

Fig. 6. Extracting the cortical bone from inside the contour, input medical image (left), inverse Laplace filter applied to the medical image (in the middle).

C. Extracting the Trabecular Bone

The final step is the extraction of the trabecular bone from inside the previously created contour. The inverse Laplace filter [16] 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. 6).

III. Experiments

The proposed method was tested on the medical images of tibia bones and vertebra of several patients acquired using conventional computed tomography. The results of applying the proposed method may be seen in Fig. 7.

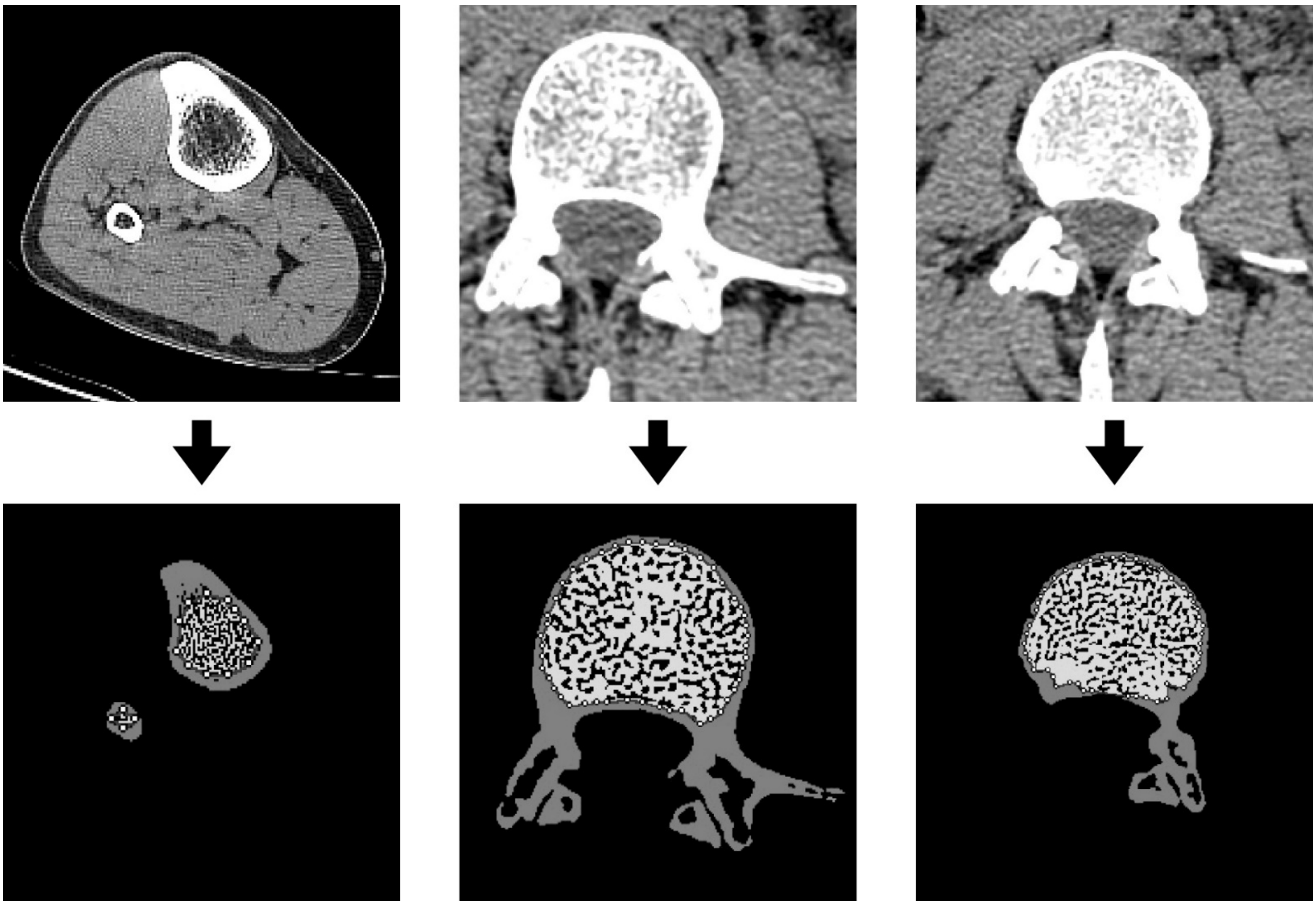

Fig. 7. The proposed method used on the medical images of a tibia bone and vertebra.

IV. Conclusions

The method proposed in this paper was tested on multiple medical images of tibia bones and vertebra from several patients and it proved capable of extracting the trabecular bone from the medical image.

The main advantage of the proposed method is that it is fully automatic, the only time it may 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 can be used when analysing the medical images of patients with osteoporosis, where it is necessary to analyse the changes in the microstructure of the trabecular bone. This method can also be used in studies, where it is necessary to analyse a large number of medical images.

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Mihails Kovaļovs, Aleksandrs Glazs. Trabekulārā kaula segmentācija, izmantojot adaptīvo kontūru
Dotajā darbā ir aprakstīta trabekulārā kaula segmentācijas metode medicīnas attēlos, izmantojot adaptīvo kontūru. Trabekulārā kaula segmentācijas metode var būt lietderīga kaulu iekšējās struktūras analīzei, ar osteoporozi slimojošiem pacientiem un kaulu medicīniskos pētījumos, kur jāanalizē liels daudzums medicīnas attēlu.
Pašlaik ir vairākas metodes, kas saistītas ar medicīnas attēlu segmentāciju, taču daudzas no tām izmanto attēlus, kuri iegūti, izmantojot augstas izšķirtspējas datortomogrāfiju vai izmantojot magnētiskās rezonanses metodi, taču šāda veida tomogrāfija ir ļoti dārga un nav pieejama visās slimnīcās. Kā arī daudzas no piedāvātajām metodēm ir pusautomātiskas, tāpēc ir nepieciešama operatora iejaukšanās segmentācijas procesā, kas pagarina medicīnas attēlu segmentācijas laiku. Šajā pētījumā piedāvātā metode ir pilnīgi automātiska un izmanto medicīnas attēlus, kuri tika iegūti, izmantojot datortomogrāfiju.
Piedāvātā metode sastāv no trim posmiem: pirmajā - medicīnas attēlā tiek izcelts kortikālais kauls. Balstoties uz Haunsfilda skalu, tiek uzdots kortikālā kaula radioblīvuma slieksnis un visi pikseļi, kuri atrodas aiz šī sliekšņa, tiek iekrāsoti; otrajā posmā, iepriekš izceltajā kortikālajā kaulā tiek veidots kontūrs, kurš adaptējas kortikālā kaula iekšpusē. Pēdējā posmā agrāk izveidotajā kontūrā tiek izcelts trabekulārais kauls, šim nolūkam tiek izmantots inversais Laplasa filtrs.

Михаил Ковалёв, Александр Глаз. Сегментирование трабекулярной кости с помощью адаптивного контура.
Данная работа описывает метод сегментирования трабекулярной кости на медицинских изображениях с помощью адаптивного контура. Сегментирование трабекулярной кости может быть полезно для анализа внутренней структуры кости у пациентов с остеопорозом и в медицинских исследованиях костей, где необходимо анализировать большое количество медицинских изображений.
На данный момент уже существует множество методов сегментации медицинских изображений, но большинство этих методов используют изображения, которые были получены с помощью компьютерной томографии высокого разрешения или с помощью магнитно-резонансной томографии, такого рода томография очень дорогая и доступна не во всех больницах. Большинство предложенных методов также являются полуавтоматическими и требуют вмешательства оператора в процессе сегментации, что значительно увеличивает время, потраченное на сегментацию медицинского изображения. Предложенный в данной работе метод является полностью автоматическим и использует медицинские изображения, полученные с помощью обычной компютерной томографии.

Предложенный метод состоит из трех этапов. На первом этапе на медицинском изображении выделяется кортикальная кость. На основе шкалы Хаунсфилда задается порог радиоплотности кортикальной кости и все пиксели, которые находятса за этим порогом, закрашиваютса. На втором этапе внутри ранее выделенной кортикальной кости создается контур, который адаптируется к внутренней стороне кортикальной кости. На последнем этапе внутри раннее созданного контура выделяется трабекулярная кость, для этого используетса инверсированный фильтр Лапласа.