USE OF SEGMENTATION AND VOLUMETRIC ESTIMATION IN THE TREATMENT OF ABDOMINAL AORTIC ANEURYSMS USING STENTS

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Abstract: The standard surgical treatment of abdominal aortic aneurysm (AAA) consists of replacing the aneurysmal aortic segment with an endograft stent in the aneurysm sac. This treatment and its outcome need to be controlled. The standard procedure is to use CT imaging to evaluate the recovery. To improve the evaluation, additional processing of the CT data could be performed to facilitate the performance of the segmentation techniques so that accurate 3D volumetric models and visualizations can be made from the abdominal area. In the present study, previously developed 2D and 3D methods were adjusted for the AAA segmentation. 2D method based mainly on Balloon technique and 3D method on Level sets. The methods were tested and compared with three patients. CT images of the patients were segmented and volume calculations and visualizations were performed on the segmented volumes. The results indicate that the stent can be segmented automatically with all the methods studied. The results show quite good correlation between the segmentation methods, however, they seem to require a certain degree of manual operation and special attention to the selection of the parameters.

Introduction

Abdominal aortic aneurysm (AAA) is a common disease in middle aged and older patients. In the modern era these aneurysms are treated by surgical procedures using endograft stents [6, 9]. These are inserted inside the aneurysm sac using interventional techniques. While analyzing the stented aneurysm sac, special importance is given to the flow column inside the stent and the amount of blood/thrombi outside the stent but inside the aneurysm sac. A common complication is that the stent loses its shape and may retract inside the original aneurysm sac. Earlier the analysis of the post stented AAA was performed using simple dimensions like length, width and breadth obtained from the CT image. Currently we are analyzing more accurate volumetric estimations using computerized techniques (segmentation and volumetry) as a pilot examination. The size of the sac is controlled using primary and repeat CT scans. Control is necessary because of several clinical reasons. Inspected matters include stent position and structure, different volumes such as inside and outside of the stented AAA. 3D modeling and visualization of the stent area is a valuable tool for controlling.

The purpose of our study was to test the usability and performance of 2D and 3D segmentation methods for accurate volumetric estimations of the contents inside the aneurysmal sac after stenting operation.

Studies applying certain segmentation techniques in the evaluation of AAA have been conducted earlier [11-13]. The purpose of our study was to test the segmentation techniques developed by our group originally for nonpathological anatomy and to further modify the techniques for the AAA application.

Material and Methods

For this purpose we chose the CT images of 3 different patients treated with 3 different types of endograft stents (a) Nitinol, b) Zenith c) Excluder). All examinations were performed on a single 3rd generation CT scanner equipped with helical imaging operations (Prospeed, GE, Wisconsin). The examinations were performed with and without iodinated contrast medium. 5 mm thick slices were taken with a gap of 10mm between the slices and from these 5mm slices axially reformatted slices were generated. The whole endograft area was visualized on these CT images. Image matrix data consisted of 512x512x48 voxels. A sample CT image from the first patient is seen in Figure 1. The cranialmost slice was taken at the level of renal arteries and the caudalmost slice was taken at the level of the bifurcation of the abdominal aorta.

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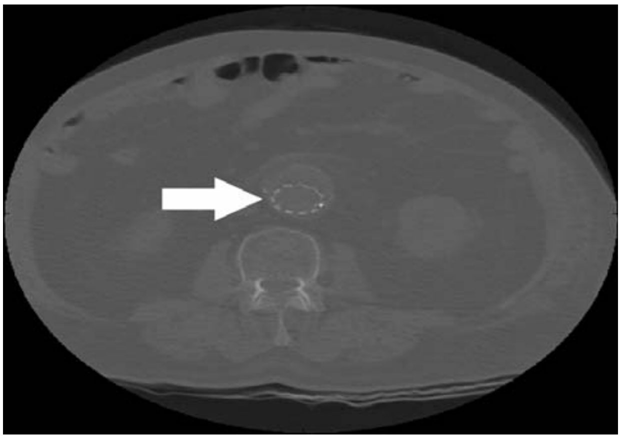

Figure 1: CT image from abdominal area. The arrow is pointing towards the stent that shows as a higher intensity circle that has some gaps. Outer boundary of the abdominal aorta is seen around the stent.

The reformatted contrast-enhanced CT images were then transferred to another PC equipped with a previously developed segmentation software based on 2D and 3D techniques operating on MATLAB. Segmentation was done with 2D and 3D methods separately.

The 2D methods utilized include thresholding, curve fitting, active contours such as Snakes [8] and morphological methods [2].

The idea in the 2D segmentation workflow was to first extract the stent because of its high intensity appearance in the CT image. However there are other high intensity areas beside the stent also visible after thresholding. To overcome this problem user is expected to give in the beginning a starting point inside the stent. This has to be done only for the first slice. With the starting point, stent can be picked up from the image. Although this requires a little user interaction, it can be considered to be acceptable. Pixels forming the stent are given to a curve fitting function [3]. This function fits an ellipse to the data points using interpolation. The outcome of curve fitting is an ellipse that presents the stent. Ellipse is initially enlarged to include all stent points and is then given as an initial curve to Balloon method [7]. With inflating force the balloon method finds the next boundary around the stent. Based on this outcome the outer boundary of the aneurysm is achieved. Result from the previous slide is used as initial configuration for the next slice and so on. Information of the location of the stent in previous slide is used to find the position of probable stent points in the successive slice. Initial curve for the balloon method is set to an ellipse between the outer boundary of aneurysm from the previous slice and the extracted stent from the current slice. This approach allows both the increase and the decrease of the estimated aneurysm area. Segmentation procedure is illustrated in Figure 2.

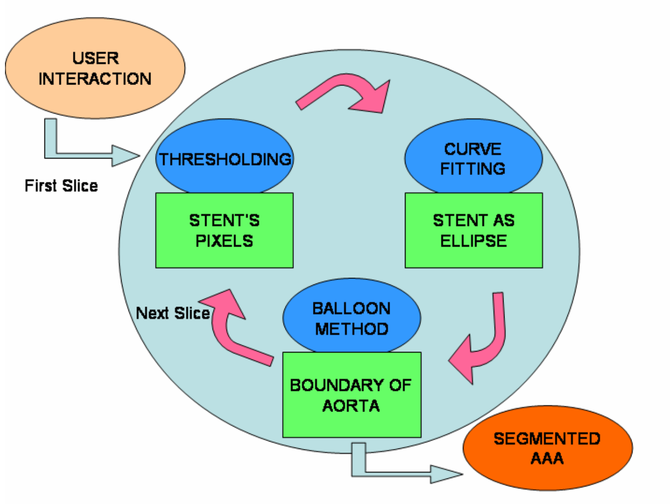

Figure 2: The segmentation workflow used in the AAA analysis. Inside the circle, the primary segmentation procedure is shown. It consists of three stages. The applied method is shown in blue oval shaped circle and the result of that stage in green box. For example first the thresholding is used in order to get the pixels representing the stent. User defines the starting point for the first slice. The result is given after all the slices have been processed by the algorithm.

The 3D segmentation method is based on the level sets implementation in 3 dimensions [4] where a n-dimensional surface is embedded in a $\mathbf{R}^{n+1}$ space [1]. A scalar function, $\Phi(\mathbf{x}, t)$ defines an embedding of a surface. In order to propagate Φ (and therefore the surface) in time, the first-order partial differential equation is defined as

$$\frac{\partial \phi}{\partial t} = F\,|\nabla \phi| \tag{1}$$

where F is a signed, scalar speed function that defines the speed in the direction normal to Φ at any point $\mathbf{x}$. The initial estimation of Φ is propagated forward in time via the up-wind scheme. The level set update equation is

$$\phi(\mathbf{x}, t+\Delta t) = \phi(\mathbf{x}, t) + \Delta t F\,|\nabla \phi| \tag{2}$$

The mean curvature of Φ is used as a speed function to propagate Φ and it is defined as

$$H = c_n \nabla . \frac{\nabla \phi}{|\nabla \phi|} \tag{3}$$

The algorithm utilizes two speed functions, image based and curvature based, for propagation. For details regarding the algorithm and its mathematical foundation the reader is referred to [1, 5].

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Few additional image pre-processing methods are also implemented which are essential due to the poor quality of clinical CT images. These pre-processing methods aim to intensify the edges within the images and on the other hand, to reduce the noise prevalent within homogenous regions.

The initial pre-processing is simply done by average filtering and median filtering along with histogram equalization. A simple function call has been included in the software which enables the user to browse the slices individually and optionally demarcate blurred regions by pressing the mouse button at points on an approximate demarcating edge. The program then interpolates a curve through all the points and forces the gray levels at these points to values outside the threshold band. This is necessitated by the presence of similar gray levels in inhomogeneous regions which need to be segmented. This can be seen in the Figure 3 below.

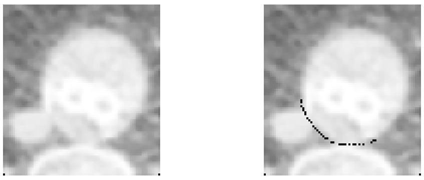

Figure 3: On the left is an example from the dataset where it can be observed that the Aneurysm and a nearby region have similar gray levels and are connected. The result of demarcating is shown on the figure to the right.

Initialization is done by defining the seed points in all the slices of interest. This increases the speed as the level set essentially propagates in a plane. While this might have a 2D essence, it actually takes into account the 3D information, thus ensuring the topological flexibility of a 3D method.

Our segmentation program includes a simple user interface. While the segmentation method is semi-autonomous, modifications for possibly faulty segmented areas can be made manually afterwards. To execute volumetric measurements, the user can scan through slices and select the starting and ending slices. The software then calculates the volume of the aneurysm and shows the results on the screen.

Results

The segmentation procedure includes the extraction of the stent and the outer boundary of the aneurysm. Thus the volumes such as that inside the stent and the total volume of the aneurysm can be calculated.

Visualizations of AAA and stent in Figures 4 and 6 are from the same patient. The calculated volume of abdominal aneurysm with 2D methods was 178 ml for the particular case. 2D segmentation result is visualized in Figure 4. A segmentation result from another patient having different type of stent is shown in Figure 5 .

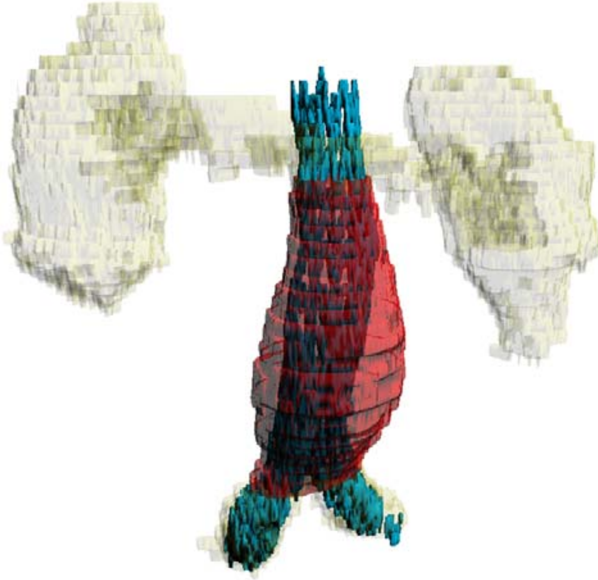

Figure 4: Segmented abdominal aortic aneurysm and stent are visualized in 3D with a 3D visualization engine developed in our institute [10]. Segmentation was done with 2D methods. Calculated volume shown in red was 178 ml. Figure also shows the segments of aorta that are above and below the stented area and the renal arteries/kidneys on both sides.

Figure 5: 2D segmentations of the AAA and the stent are visualized. The stent type is different from that shown in Figure 4.

Using the 3D level set algorithm the volume of the entire aneurysm including the stent and its internal volume is calculated to be 185ml. 3D segmentation result for the same patient as in Figure 4 is shown in Figure 6. It takes approximately 10 minutes for the 2D and 14 minutes for 3D method to segment a single data set on basic 3 GHz processor desktop with 1024 MB memory. This time also includes possible manual segmentation and interaction.

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Figure 6: Segmented abdominal aneurysm using 3D methods. Segmented material was the same as in Figure 4.

Discussion

Segmentation of three types of stents from the CT data was achieved by the studied algorithms. Segmentation task of the AAA was, however, quite difficult because of the low contrast as can be seen from the histogram of a sample slice from the data and the presence of noise in the axial CT slices. These conditions produce absence of strong edges, which are desirable for successful segmentation results.

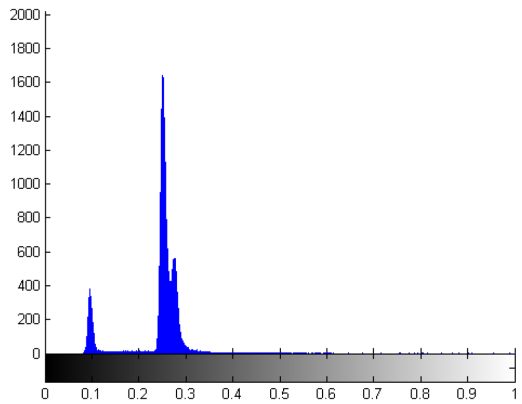

Figure 7: Histogram of the CT-data in Figure 1. As can be seen the image data is concentrated in two narrow regions. The dynamic range of the image gray levels is constricted. Thus appropriate equalization procedures have to be adopted to gain some meaningful contrast.

Abnormal shapes of the aneurysm can as well make segmentation complicated. Due to these difficulties, developed segmentation methods have to be quite flexible. A priori knowledge for the user defined input initial parameters can be used when patient material increases.

2D methods turn out to be quite good for the segmentation of AAA. Balloon method is a fine choice due to its characteristics. The wanted result in 2D is circle shaped closed curve as is balloon in the beginning. Even if aneurysm has weak outer boundary with rigidity term big enough contour will not leak outside of the aneurysm. However physiological variations and poor contrast make segmentation tricky. Careful investigation of the adjusting parameters of the balloon method will help to avoid incorrect results. Although 2D methods find the AAA, the result has to be validated with 3D visualizations.

In the 3D method it was observed that at certain regions of the data leakages occurred from the aneurysm sac. This can be attributed in some part to the poor resolution and quality of the CT data, since the axial resolution of each slice is 5mm and further, the inter-slice spacing is 10mm. Thus in certain instances dissimilar regions of similar gray-levels, though distinguishable on a single slice seem to overlap when the whole 3D image information is taken. As in this case, the aneurysm region expands and in effect expands also over the unwanted region. Though the result obtained by the 3D method has some errors in it, it should be noted that the implementation of the algorithm employs general speed functions and stopping conditions. In the future, work will be aimed at incorporating more specialized stopping conditions, constraints and criteria for propagation, so as to suit the aneurysm data. However, the 3D segmentation may provide easier approach for inexperienced users since it provides more automated approach.

Using this technique we observed sufficiently good volumetric estimations and 3D reformations.

This study forms a part (pilot study) of an ongoing larger study where CT images will be analyzed from 300 patients stented for AAA. In this pilot study with three patients although good volumetric results were observed they were statistically insignificant. We intend to perform volumetric estimations in all 300 patients and thereafter perform a larger statistical analysis on the basis of which we shall be able to predict success or failure after AAA stenting. Also we intend to calibrate these volumetric algorithms using a standard phantom and performing inter and intra observer studies. During this stage we will also be working towards improving time consumption of the segmentation methods. Based on the future result from this larger study we should be able to predict the actual importance of these techniques in clinical analyses of AAA treatment.

Future work includes developing more automated and easier to use methods. Reliability of the segmentation results shall increase when larger number of patients will be included in the study.

Conclusions

Both 2D and 3D methods proved user-friendly easy to use, relative fast and accurate for making volumetric estimations of AAA after stenting. We believe that our software will become useful in making clinical decisions and evaluating the prognosis in these patients. These kinds of methods are warranted to be able to analyze large patient materials.

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