Determination of the variation of the intima-media thickness and the diameter of arteries from echocardiographic ultrasound image sequences

Diego F. dos Santos\textsuperscript{a}, Marco A. Gutierrez\textsuperscript{b}, Eduardo T. Costa\textsuperscript{a}\textsuperscript{*}

\textsuperscript{a} DEB/FECE and CEB/UNICAMP, Caixa Postal 6040, CEP 13084-971 - Campinas, SP, Brazil
\textsuperscript{b} INCOR/USP, Av. Dr. Eneas de Carvalho Aguiar, 44, CEP 05403-900 - São Paulo, SP, Brazil

Abstract

The intima-media thickness (IMT) of the arteries serves as a marker of generalized atherosclerosis and several studies have shown a positive association between IMT and incident stroke. Several software systems have been developed to detect IMT and artery diameter, with some trying to obtain and show these values automatically without success because the operator normally has to do some later adjustments. Our proposed method shows that a totally automatic measurement is possible. This method is part (plugin) of a software called EchoLab that aims to be a repository of algorithms and methods used in echocardiography. We have tested the software with a set of images of a home-made phantom and our results show that it accurately measured the inner diameter of the silicone tube of the phantom (error less than 5%). We have also tested the software with real echocardiographic images and show the results for a set of 244 frames. Specialists at INCOR/USP are now validating the software.

Keywords: Intima-Media Thickness; Ultrasound Imaging; DICOM

1. Introduction

Cardiovascular diseases are the leading causes of death in Brazil. According to the Brazilian Ministry of Health, in 2002, 46.21\% of deaths occurred in Brazil were due to coronary heart diseases. The disease that most contributed to this figure is atherosclerosis, a pathology of arteries that is characterized by flow decrease or total obstruction of vessels, due to the accumulation of fat in the inner surface of the wall of the arteries.

B-Mode ultrasonography is often used to see the morphology of arteries and is a non-invasive and reliable technique to identify preclinical atherosclerosis. The intima-media thickness (IMT) of the arteries serves as a marker

* Corresponding author. Tel.: +55-19-3521-9274; fax: +55-19-3289-3346.
E-mail address: educosta@ceb.unicamp.br.

doi:10.1016/j.phpro.2010.01.053
of generalized atherosclerosis and several studies have shown a positive association between IMT and incident stroke [1].

It is very difficult to measure the intima-media thickness due to speckle in ultrasound images [2] (Fig. 1) and its very small size (usually 0.40 mm to 1.14 mm). Clinicians are used to determine this thickness (IMT) manually, which is clearly not an accurate method. They may also choose three images at systole and three images at diastole phases of the cardiac cycle (from a sequence of echocardiographic images) considered to be the best images and determine IMT automatically from those chosen six images.

Structures that are visible in an ultrasound artery image are shown in Fig. 1. Arteries are composed by 3 main layers:

- Intima: the inner layer and is directly in contact with blood.
- Media: this layer can not be seen, separately, in ultrasound images.
- Adventitia: is the outer layer and the external limit of the vase.

Fig. 1 B-Mode ultrasound image of an artery showing possible arterial diameter and intima-media thickness. It is difficult to clearly define structures due to speckle in the image and small impedance differences between them.

In this paper, we present an automatic method to measure the intima-media thickness and the arterial diameter from a complete sequence of B-Mode ultrasound images of arteries. The main objective is to automatically generate two complete curves of the arterial diameter and the intima-media thickness variation. The clinician must only choose a Region of Interest (ROI) in the first frame of the sequence. Then, this ROI is applied to all frames and the arterial diameter and IMT variations are determined.

2. Methods

The main algorithm that was used to detect the desired variables (artery diameter and IMT) is presented in Fig. 2. The image is prepared with the necessary information on pixel value and known distances. It is then passed through threshold and Gaussian filters. From that prepared image, we generate three images that will highlight the desired structures: proximal, intima and media-adventitia). This is explained in detail in the next sections.

Fig. 2 Main steps applied to the ultrasound image in order to detect vessel walls and measure artery diameter and IMT.
The default ultrasound image format used in the software EchoLab is DICOM (Digital Imaging and Communications in Medicine), but our software can read and process almost all kinds of image files. To make possible measurements in the image, we need to know how the image pixels are related to the distance between structures. DICOM files have a tag that gives us this kind of information automatically. On the other hand, when we are dealing with other types of image files, we use the marks in the image that represent a certain distance. The operator must draw a line through these marks and insert (via keyboard) to the software this well known distance (usually 10mm).

The quality of ultrasound images are normally very poor compared to other image modalities and, to reduce the noise and undesirable edges that could be detected, the image pass through an erosion filter. We divide the image in two sections: from the initial curve (in the center of the artery) to the proximal side, and from the initial curve to the distal side. For each section, we measure the average value in the neighborhood of a pixel (3x3) and the average value along the lines of the image. With these values, we construct a threshold value to the distal and the proximal sides:

- Distal: to highlight the distal side (media-adventitia structure), all pixels in this section that are below the threshold will become 0 (black).
- Proximal: to highlight the proximal side, all pixels in this section that are below 70% of the threshold value (empirical finding) will become 0 (black).

The output image will be normalized in two sections: from the center of the artery to the proximal side and from the center of the artery to the distal side. To generate an image that emphasizes the intima interface, we get the distal threshold and apply it to each pixel (in the distal section). When the pixel value is greater than the threshold, we change the pixel value to 0 (black). So, we have an image without the media-adventitia interface and with the intima interface highlighted. As it occurs with the proximal and distal images output, the intima image is also normalized in sections (proximal and distal see below).

All images generated by the Threshold filter will become an input to a Gaussian filter. We used an anisotropic Gaussian filter with the following sigma parameter values for the X and Y directions:

\[
\begin{align*}
X &= 3.0 \\
Y &= 1.15
\end{align*}
\]

As all interfaces we want to detect are aligned horizontally, we can choose a higher value for the sigma parameter in the X direction. The value of the sigma parameter in Y direction increases the range for capture of an edge in the image.

The output image generated by the Gaussian filter will become an input to the Gradient module. We used the masks shown in Equations 1 and 2 and calculate the gradient magnitude.

\[
G_{D,x} = \begin{bmatrix}
-0.7 & 0 & 0.7 \\
-1 & 0 & 1 \\
-0.7 & 0 & 0.7
\end{bmatrix}
\]

*Equation 1. Convolution Mask – Gradient in the X Direction.*

\[
G_{D,y} = \begin{bmatrix}
-0.7 & -1 & -0.7 \\
0 & 0 & 0 \\
0.7 & 1 & 0.7
\end{bmatrix}
\]

*Equation 2. Convolution Mask – Gradient in the Y Direction.*
The gradient magnitude of all images is inverted and, as before, this output (magnitude) is also normalized in two sections (proximal and distal).

We construct three images emphasizing the three interfaces (Fig. 3): proximal, media-adventitia and intima.

After all steps to prepare the image are completed, we can move the points toward the desired edges. We get the proximal magnitude gradient image and move all points of the initial curve until we get a vector with the up direction representing an edge. With this approach, we make sure that all points will be near an edge and we can use a deformable model to fit this curve to the desired edge. We use the Discrete Dynamic Contour Model proposed by Lobregt [3] and the curve, after a few steps, is attracted by the proximal edge. We get the distal magnitude gradient image and move all points of the initial curve until we get a vector with down direction. After a few interactions all points will be positioned in the desired edge. We get the intima magnitude gradient image and with the points positioned in the media-adventitia interface (achieved in the previous step) we “pull up” all points toward the intima interface (the next edge that appears in the magnitude image).

3. Results and Discussion

In Figure 4 we present the initial image (from an image set composed by 244 frames of echocardiographic ultrasound images) and the initial points (straight line in the center) used to do the measurements.

After a few seconds, EchoLab shows the results of the measurements for the sequence of frames (Fig. 5). We can see in Fig. 5 the curve of the diameter variation of the artery as well as the possibility to see the Intima-Media Thickness curve (in a second tab). With these data in the EchoLab software, we can also see the average value (straight horizontal line) of the diameter (Fig. 6) and of the Intima-Media Thickness (Fig. 7).

The average values obtained were:

- Diameter = 5.8875 mm.
- Intima-Media Thickness = 0.4722 mm.

It is interesting to note that available software [5] for clinicians make use of 6 images chosen at three particular instants of the cardiac cycles (three in systole and three in diastole) and, after manipulation, the software calculates
the IMT. Our results are in close agreement to the results of the specialist using this software with the difference that ours is totally automatic.

![Fig.5 Screenshot of EchoLab showing the results for the diameter variation during several cardiac cycles.](image1)

![Fig.6 The average diameter value (straight horizontal line) obtained from the artery diameter variation.](image2)

![Fig.7 The average intima-media thickness (straight horizontal line) obtained from the artery intima-media thickness variation.](image3)

We have obtained a set (130 frames) of images of a silicone tube immersed in a home-made paraffin tissue-like phantom [4], shown in Fig. 8. The tube internal diameter is 4 mm and its ultrasound image (Fig. 9 left) does not present a detectable intima-media interface. This phantom is part of a simulator circuit to test Doppler image equipment. Saline water circulates in a closed circuit including a reservoir tubing and phantom using a peristaltic pump. The image set was obtained using ultrasound commercial equipment GE® Logiq-Book. Echolab software detection of the silicon tube diameter can be seen in Fig. 9 (right). The average calculated diameter was 3.803 mm. Fig. 10 shows the diameter variation curve.
4. Conclusion

In this paper we have presented an automatic method to measure the diameter as well as the intima-media thickness variations and respective average values of arteries from a sequence of echocardiographic images. The software operator (clinician) has only to draw an initial curve in any image, and all steps are performed automatically, without any other intervention. To our knowledge, all the known software aiming at measuring these structures in such totally automatic way fails to do so. The operator always must add some “fine adjustments” afterwards [5].

The results for the measurement of a silicone tube diameter of a home-made phantom showed that the error was less than 5% if we take the real tube diameter as 4 mm (the software calculation resulted in 3.803 mm). We have also shown the results for a set of real echocardiographic images and have also tested it in our laboratory with several real image sequences with similar results. Specialists are now using our software in order to validate it and compare the results with those from established methods currently in use. From our point of view, with our method time can be saved and results can be very accurate (as seen with the measurement of the phantom silicone tube shown in Fig. 10). The clinician does not need to choose six images from specific cardiac cycles, as he is used to do, choosing only one image of the sequence to perform the analysis [5]. Unsuitable images of the sequence are
discharged without prejudice to the analysis since sequences are composed of at least 100 images in different cardiac cycles.

Acknowledgments

The authors would like to thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil.

References

[1] L. E. Chambless, A. R. Folsom, L. X. Clegg, A. R. Sharrett, E. Shahar, F. J. Neto, W. D. Rosamond and G. Evans, “Carotid wall thickness is predictive of incident clinical stroke”, American Journal of Epidemiology, vol 151, pp. 478-487, 2000.

[2] C. P. Loizou, C. S. Pattichis, M. Pantziaris, T. Tyllis, A. Nicolaides, “Quality evaluation of ultrasound imaging in the carotid artery based on normalization and speckle reduction filtering”, Med. Biol. Eng. Comput, pp. 414-426, 2006.

[3] S. Lobregt and M.A. Viergever, “A discrete dynamic contour model”, IEEE Transactions on Medical Imaging, vol 14, n. 1, pp.12-24, 1995.

[4] O. C. Coiado and E. T. Costa, “Simuladores para medição de fluxo de líquidos por efeito Doppler para controle de qualidade de equipamentos de ultra-sonografia”, Proceedings of the 21st Brazilian Congress on Biomedical Engineering, p.1-4, 2008. (in Portuguese)

[5] M. A. Gutierrez, P. E. Pilon, S. G. Lage, L. Kopel, R. T. Carvalho and S. S. Furuie, “Assessment of carotid diameter and wall thickness in ultrasound images using active contours improved by a multiresolution technique”, Proc. SPIE, vol. 4683, 2002.