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The detection of atherosclerotic plaques in B-images

Jakub Skácel[1]
Jiří Blahuta[2]
Jiří Martinů[3]

[1] Silesian University in Opava; Bezručovo nám. 13, 74601 Opava; jakub.skacel@fpf.slu.cz
[2] Silesian University in Opava; Bezručovo nám. 13, 74601 Opava; jiri.blahuta@fpf.slu.cz
[3] Silesian University in Opava; Bezručovo nám. 13, 74601 Opava; jiří.martinů@fpf.slu.cz

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Abstract This work addresses the possibility of detecting the risk factor of atherosclerotic plaques using diagnostic ultrasound. The aim is to show methods to detection the risk factor of plaque what are recently known. The first part describes role of the diagnostic ultrasound and its modes and the artifacts that can occur. The second part describes atherosclerosis and its risks followed by displaying of the plaques in B-images. The last part describes the investigated data and a pilot study with developed MATLAB-based software with cooperation of an experienced sonographer to compare features in B-MODE and from histological patterns. Also will be discussed and improved the adaptability of the software for new tissues.

Keywords Ultrasound, B-MODE, atherosclerosis, atherosclerotic plaques

1. INTRODUCTION

The aim of this work is to determine the risk factor of atherosclerotic plaque using diagnostic ultrasound. The records are from nearly 2,000 patients who underwent an examination. This involves data from several different sources and before processing it begins, individual tables, ultrasounds, histology, and other sources need to be combined, the end of which should result in a patient database containing all information about each patient, which will be available to us.

According to the information available to me, such a large database still does not exist. Most atherosclerosis examinations were performed on the order of smaller samples. The oldest data is from 2006, so the long-term progression of plaque in certain patients will be monitored as a differential diagnostics.

2. ULTRASOUND AS A DIAGNOSTIC TOOL IN MODERN MEDICINE

Diagnostic ultrasound is among the imaging methods used in medicine for diagnosis. The most common type of ultrasound examination is done, for example, during pregnancy to monitor the fetus. Ultrasound is also used in other fields of medicine, e.g. cardiology, neurology, ophtalmology, etc. Using diagnostic ultrasound in neurology raised up a new field of neurosonology. There are some crucial advantages of ultrasound.

- It is a widely used, easy to use and noninvasive
- The examination takes place in direct contact between the physician and patient
- The relative low cost in comparison with another modalities, e.g. MRI or SPECT
- No ionizing radiation
- It clearly shows soft tissue
- At present there are no known risks or side effects of ultrasound examinations for adult patients or the unborn

Therefore, the ultrasound can be also used for therapeutical applications. These applications are not topic of this paper.

2.1 Basic physical background of the ultrasound

In general, the ultrasound works on the basis of ultrasonic waves that pass through or are reflected from material with different density. The ultrasound is considered as a longitudinal mechanical wave above the threshold of human audibility from 2 up to 30 MHz. Every environment, whether alive or dead, is characterized by several parameters from an acoustic perspective. The diagnostic information is obtained by capturing, processing and displaying ultrasound signals reflected from the tissue interface. There is the effect of attenuation of the waves. The attenuation depends on the frequency of ultrasonic vibrations and plays an important role in the choice of the imaging frequency.

- Each tissue is characterized by several properties: Acoustic impedance
- Attenuation of ultrasound waves
- Propagation speed, which does not depend on frequency but on the material

On Fig. 1 is shown different speed of ultrasound in different materials measured in 37 °C.

Material (37 °C)	Speed of sound (m/s)
air	353
lung	600
water	1550
blood	1560
muscle	1600
bone	4080

Fig. 1 Approximate sound speed of the ultrasound in various materials

2.2 Modes of ultrasound imaging

A-Mode (Amplitude) is 1-D imaging, typically a signal only from one transducer. There is most simple ultrasound mode. Individual reflections registered by the ultrasound probe are displayed on the monitor as impulses on a timeline. The amplitude of the impulses corresponds to the intensity of the reflected ultrasonic waves. A-mode currently has only limited use especially in ophthalmology. A-Mode is of course the basis of all other methods, because they can be visualized as individual “beams” in the A-Mode, where the graph valuesare converted into grayscale.

B-Mode (Brightness) represents the basic of tomographic imaging. There are basically two types of imagery – static and dynamic. Static imagery is historically older, technically easier and has long since been abandoned due to the affordability of electronics and computer technology that allow the possibility of routine dynamic imaging. Measuring was done using a single transducer, which was moved over the patient’s body. The image was obtained through the gradual summation of individual measurements.

Dynamic B-Mode – in dynamic imaging, there are a series of transducers in one probe that work in unison and whose echoes are evaluated so that we see the final image as the images taken in real time. There is clearly the most common approach of imaging today.

M-Mode (Motion) is used to examine the movement of anatomical structures, especially the heart. In principle, it is really nothing more than a one-dimensional record taken at regular intervals. The measured echoes are then encoded into grayscale and imaged one after the other over time.

Fig. 2 A-, B- and M-MODE of ultrasound imaging

A 3-D image can be obtained in principle by two means, with a three-dimensional probe and reconstruction.

Three-dimensional probes – generally, the three-dimensional probe does not ordinarily differ from the two-dimensional probe, only the transducers are not arranged in line but in an array. These probes can then scan data from the whole volume in a relatively short time, so it is even possible to do imaging in real time, sometimes called as 4-D imaging. The disadvantage is that the probes are relatively awkward, and so it is necessary to ensure good contact with the patient’s body with a relatively large surface.

Reconstructive procedures – a three-dimensional image can be obtained by the mathematical processing of images taken by a probe. The first attempts consisted of attaching the probe to a frame with controlled movement and all processing consisted only of synchronizing the movement and recording the images into memory. A system of sensors detecting the position of the probe in space was more flexible. Using a series of profiles supplemented with information about the position of the probe, the value of individual voxels could then be counted. Modern devices are more sophisticated; the attending physician only “passes” the probe freely over the area of interest and the profiles obtained are used to mathematically determine first the position and then the three-dimensional images is reconstructed.

2.3 Artifacts of ultrasound imaging

During an ultrasound examination, various artifacts[1] can be occured. These artifacts can simulate pathological phenomenon and result in meaningless treatment. Most of the artifacts can be identified using several methods:

- Changing the device settings
- Changing the position of the patient
- Performing the examination on multiple planes

The following Fig. 3 shows an example of artifacts[2].

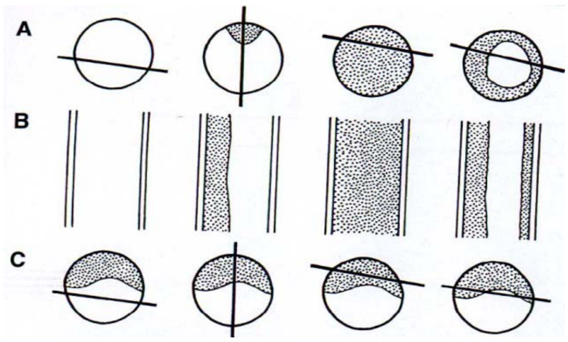

Fig. 3 Artifacts

What various artifacts cause:

- The speed of the propagation of ultrasonic waves is approximately of 1540 m/s, but slightly differs in different tissues. Reflections arrive sooner from tissues in which the waves run faster, so that the tissue appears closer than it really is.
- Impulses in tissues do not propagate rectilinearly and they do not reflect only once, but their divergence refracts from the original direction at the interface of different acoustic impedance. Through refraction, impulses not originally present can also get into the central beam. Multiple reflections occur when ultrasonic waves are reflected perpendicular to propagation from strong waves at the constructed interface, namely between the interface and the probe and between the walls and a formation like a cyst.
- Acoustic shadowing is formed behind strongly reflecting surfaces, so we cannot see the structures behind it. See Fig. 3 below3.

[1] http://www.slideshare.net/ansaripv/ultrasound-artifact
[2] http://www.cmp-brno.cz/Ultrazvukove-vysetreni.html
[3] https://www.med-ed.virginia.edu/courses/rad/edus/text%20jpegs1/4b-gallstone.jpg

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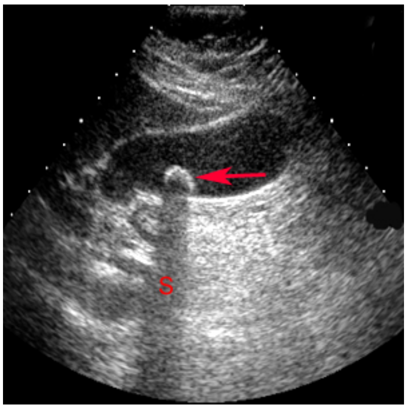


Fig. 4 An example of acoustic shadowing

3. ATHEROSCLEROSIS – DETECTION, SYMPTOMS AND RISK

In this disease, atheromatous plaque is deposited on the arterial wall. The wall thickens and the throughput (cross-section) of the artery shrinks. Atheromatous plaque gradually hardens (mostly due to the binding of calcium to the fat components of atheromatous plaque), and the result is a reduction in the elasticity of blood vessel walls. It is a chronic inflammatory process that practically starts in childhood and continues to develop with age. So, atherosclerosis grows slowly and quietly. A long period of time can go by without any detectable symptoms. The speed of its growth depends on the presence (absence) of risk factors; some of them are shortly described below. This gradually leads to the restriction of blood flow through the affected vessel and an insufficient supply to target organs and tissues.

Manifestations vary according to the part of the body affected:

- Inadequate perfusion of the tissues is manifested by stinging and cramping in the leg muscles when walking or chest pain during exertion.
- The complete occlusion of the corresponding arteries results in myocardial infarction, cerebral stroke or circulatory disorders of the lower extremities.
- Atherosclerosis significantly changes the strength of the vascular wall. It may be that a rupture occurs over time or, at best, the affected area only becomes bulbous. This creates an aneurysm.

The most influential factors are smoking (nicotine narrows blood vessels), hypertension, metabolic disorders of fats and cholesterol, and diabetes. Other risk factors are obesity, stress, little exercise and increased clotting ability. The method of treatment is therefore directed towards eliminating these risk factors. The following Fig. 4 shows an example of progression of atherosclerotic plaque[4] within the differential diagnostics.

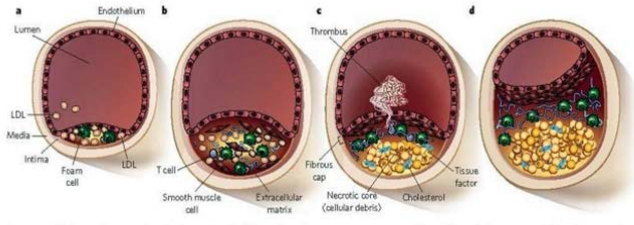


Fig. 5 The progression of atherosclerotic plaque in arterial wall

3.1 Stable and unstable plaques

In medical practice are commonly distinguished stable and unstable plaques. Stable plaque has a low fat content and commonly does not tend to rupture. Unstable plaque is rich in lipids and often "cracks". It results in thrombosis, which can bring about an acute stroke. Unstable plaque is therefore dangerous in terms of acute complications (stroke and hemorragy).

3.2 Examination of carotid arteries

There are no special requirements for the examination, only lying down, and takes about 20-30 minutes (depending on the severity of the findings and viewability of the tissue). The examination is painless. The results are already known during the examination. The main indicator is the IMT value (Intima-Media Thickness)[5], which represents the height of the plaque, see Fig. 6.

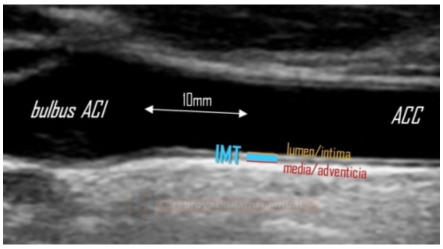


Fig. 6 a. carotis interna, a. carotis communis, IMT

3.3 How can we prevent the atherosclerosis

There are many factors what can we influence, e.g.:

- The daily cholesterol intake should not exceeds 300 mg.
- Significant restrictions on alcoholic beverages. For people suffering from hypertension, it is also necessary to reduce the intake of salt.
- Body weight should be kept between 18.5 to 25.0 BMI.
- Regular exercise at least 30 minutes a day, four times a week.

If the atherosclerosis is in advanced form, one of the following solutions are required:

- A medication used is called hypolipidemic agents.
- Cathetrization is used where a catheter (wire) is introduced through an artery into the coronary vessels. A balloon at the tip of the catheter is inflated to stretch the blood vessel and a so-called stent is introduced at that place. The stent is a kind of spring that keeps the vessel open.

[4] https://classconnection.s3.amazonaws.com/107/flashcards/247107/jpg/biochem550_atherosclerotic_plaque_formation1337024186311.jpg

[5] http://cmp-manual.wbs.cz/

- The clogged area of the vessel can be bypassed during an operation, using a piece of vein usually taken from the leg. The areas clogging the flow of blood are therefore bypassed with new vessels.
- Another solution consists of a procedure in which the inner layer of the vessel wall at the narrowed section is removed. Surgery has its risks and a stroke occurring during it cannot be ruled out.

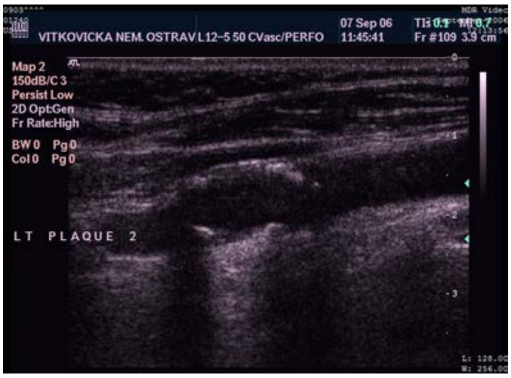
4. DATA PROCESSING

The processed data comes from several sources, which currently form one large database of patients with atherosclerosis. The database will contain complete information about the patients and their diagnoses. Currently, the database contains nearly 2,000 patients and is still growing. The data for some patients are already complete (questionnaire, ultrasound, ultrasound for resected plaque and histological analysis). These patients will be the most important for future research, but other patients with only parts of the information complete are also important.

Fig. 7 CD with ultrasound images, histological patterns and other data

4.1 Used ultrasound B-images to data processing

Ultrasounds images have been taken in 2006 and each examination was subsequently stored on a single CD, are gradually being copied to disk. Subsequently the images was manually separated and chosen images which are important for further processing (images with atherosclerotic plaque). These patients will be gradually invited for another examination after 10 years, where a new ultrasound image will be taken and information obtained about any health problems and the progress of the disease.



Fig,. 8 Ultrasound image of lognitudinal section of artery with growing plaque

4.2 Plaques in vitro

The resected plaques were inserted into a tube and ultrasound performed on 12 profiles of the plaque. The plaque is clearly visible in these ultrasounds and should become more recognizable during processing than ultrasounds taken directly from the patients.

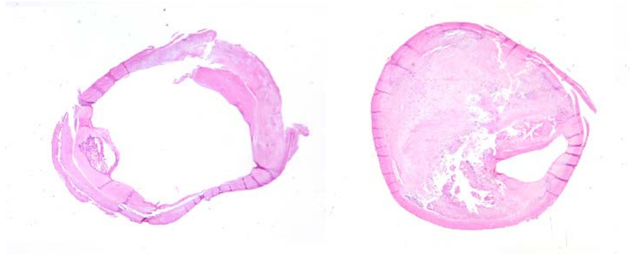


Fig. 9 Digitized patterns preserved from in vitro histological plaques

From histological patterns is possible to determine the composition of the plaque and the ratio of cholesterol and another part, see Fig. 4 for details.

4.3 A pilot study on B-images

Early diagnostics of atherosclerotic plaques is one of crucial roles in prevention of ischemic stroke. Recently, in 2016, was performed a pilot study focused on detection and analysis of atherosclerotic plaques in B-images. There are some crucial limitations to detection and analysis of atherosclerotic in B-images.

- each plaque has a unique composition, shape and size
- there is no normality of displaying the echogenicity

The first limitation is based on the origin and the progression of the plaque. In other words, each plaque has different progression in the course of time. The risk level of the plaque progression is given by grade of arterial stenosis. See Fig. 9 which shows the examples of displayed B-images with atherosclerotic plaques.

5. B-MODE ASSIST SYSTEM SOFTWARE

The study was performed using own developed MATLAB-based software B-MODE Assist System which was developed originally for transcranial B-images. The core of the algorithm is based on binary thresholding in selected ROI. The goal of this program is to observe how the echogenicity is changed depending on threshold. The software was successfully tested on transcranial B-images to detection various diagnoses, e.g. Parkinson‘s Disease, echogenicity of ncl. raphe and ncl. lentiformis. Also this software has been tested to finding iron in post-portem brain and parenchyma disorders and results have been published.

The principle of the software is universally usable to many different ROIs. Within the pilot study was investigated how to use this algorithm to detection and analysis of atherosclerotic plaques in B-images. To analysis of atherosclerotic plaque we need a special ROI for each plaque. Thus, there is no problem with implementation of free-hand ROI in which the echogenicity is analyzed. The main barrier is the fact the ROI is not equal and the results cannot be compared due to the principle of this algorithm. Moreover, in B-images does not exist any objective marker how to distinguish the plaques. So, the plaques could be distinguished by size, shape, heterogeneity, etc. The future work should be focused on finding some reliable markers to accurate and reliable classification of the plaques. There is crucial to early diagnostics of the plaques and their risk level. In this pilot study were examined total of 23 images of atherosclerotic plaques with different grade of heterogeneity. The goal of this study was to find some features corresponding to histological patterns. The images were classified depending on heterogeneity grade by an experienced sonographer. Unfortunately, no satisfactory correlation between B-images and corresponding histological plaques was found. As a consequence of these results is needed to find another features how to reliably distinguish plaques to early diagnostics using B-MODE.

5.1 Using the software to the pilot study

To investigation of analysis of atherosclerotic plaques on B-images has been performed pilot study mentioned above. The goal of this study is to find any feature how to distinguish heterogeneous and homogeneous plaques.

The results confirmed limitation mentioned above. Therefore, there is no way how to compare decreasing number of echogenic pixels (area) if the initial area of the ROI is variable. See the following Fig. 10 and Fig. 11 which shows investigated results.

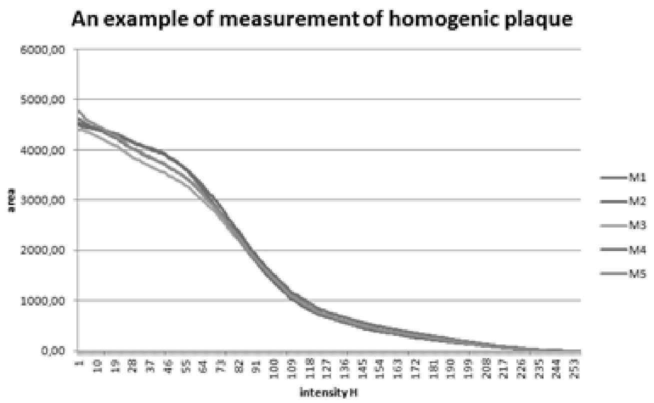


Fig. 10 Decreasing number of echogenic pixels depending on threshold for homogeneous plaques

Similarly for heterogenic plaques as follows.

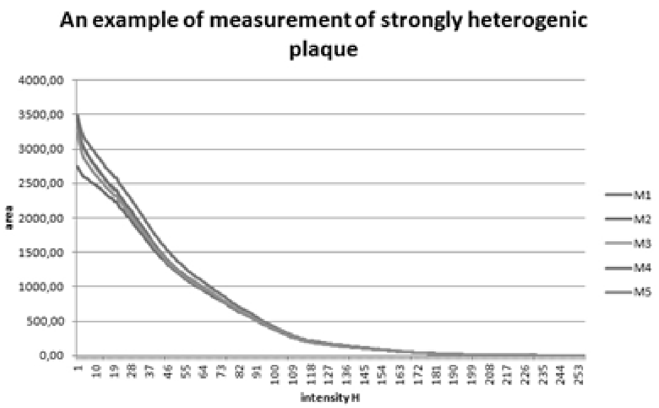


Fig. 11 Decreasing number of echogenic pixels depending on threshold for homogeneous plaques

Although it seems that differences are minimal, it is necessary to consider different area of the ROI. So, this comparison is not objective in general.

These results proved that is needed to find different feature how to distinguish plaques independently on its area.

6. RESULTS AND FUTURE WORK

The aim of this study is to observe how to detect atherosclerotic plaques in ultrasound B-images in comparison with histological patterns. Currently is available a large database of more than 2000 histological patterns with known diagnoses. Also is available a set of B-images from axial and longitudinal section.

These images have been used for a pilot study focused on finding some features how to distinguish the plaques in B-images in comparison with histological patterns. To this study is used own developed software based on echogenicity detection in a selected ROI. There some crucial limitations which cause the atherosclerotic plaques cannot be analyzed with this software due to plaque anatomy. Within this study was investigated total of 23 images to observe if exist some features to reliable detection of atherosclerotic plaques. Due to mentioned limitation no reliable features has been recognized and also was performed the statistical analysis of which results proved that is needed to find different features according to composition, size, shape and heterogeneity of the plaque in digital ultrasound B-images.

In any case, the study was rewarding experience and the topic to future work. Finding a way how to reliably detect plaques in B-image with equal reliability as on histological patterns will be very useful to early diagnostics of the progression of plaques and the early prevention of ischemic stroke.

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