Deep venous thrombosis: database creation and image preprocessing

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Abstract— **Deep Venous Thrombosis (DVT) is a major national health problem. Its progression to a pulmonary embolism can lead to significant mortality. DVT is a frequent, severe and often under-recognized diagnosis for critically ill patient. Many factors can increase the risk of DVT: immobilization, cancer, age, surgery, previous DVT, hormone, thrombophilia, etc. Ultrasonography is mostly performed for its diagnosis because it is easy, immediate and non-invasive. In our project, the main goal is to determine the possible correlations between the blood clot structure and the DVT triggering factors. To characterize its structure, we decided to combine ultrasound and elastography imaging. The latter technique is already used to diagnose other diseases such as liver fibrosis and gives promising results to date animal blood clot. This paper explains how we create our database using Toshiba's system. Our data are screenshot images that have to be prepared for further processing such as texture characterization.**

Index Terms— **Deep Venous Thrombosis (DVT); clot; ultrasound imaging; elastography; Human Machine Interface (HMI), image preprocessing**

I. INTRODUCTION

The formation of a blood clot in a deep leg vein is called the Deep Venous Thrombosis (DVT) [1]. This disease is less known than artery pathologies such as myocardial infarction or cardiovascular diseases. However it may also have deadly consequences [2]. A clot fragment can come off, travels to the lung and causes a Pulmonary Embolism (PE). Three main symptoms can alert a person to the development of a DVT: calf or ankle swelling, leg warm to the touch and leg pain or tenderness. However, these signs are not specific to DVT and some patients suffering from DVT may have none of these symptoms. This fact makes this disease more dangerous and difficult to be diagnosed.

II. DATABASE CREATION USING TOSHIBA'S SYSTEM

In our project, ultrasonography and elastography have been selected. This section describes our system and its outputs with our database.

A. Blood clot imaging techniques

Several techniques exist to display the venous blood network and to analyze a blood clot in vivo [5]: Phlebography, Magnetic Resonance Angiography (MRA), Computed Tomography Angiography (CTA) and Doppler ultrasonography. The authors of [6, 7] compare the performances of their approaches (sensitivity, specificity, positive and negative predictive values) to diagnose DVT. Their obtained results are similar. Doppler ultrasonography has a lower quality image but it provides direct imaging and localization. This test is also non-invasive, relatively cheaper, less time-consuming, repeatable and without ionizing radiation exposure. Moreover, the different ultrasound systems [1] (Toshiba, Siemens SuperSonic Imagine …) have several operating modes that are, especially, useful to diagnose a DVT and to characterize a blood clot.

B. Blood clot detection and characterization using ultrasound

1) Brightness-mode with 2 dimension imaging (B-mode 2-D)

The B-mode 2-D is the default and the most intuitive mode: it is a 2 dimensional cross sectional view of the portions of the organs or the tissues that are intersected by the scanning plane. The shape of the field (sector, rectangular or trapezoid) depends on the probes used. The chosen probe to perform venous examination is a 5-10 MHz linear probe. On a gray scale, high reflectivity (as tissue) is colored white and for no reflection (as blood) is colored black. Two ultrasound imaging findings can point out the presence of a blood clot in a vein: the relative incompressibility of the vein and an echogenic intraluminal material [3].

In most case, the blood clot is echogenic. At the beginning of a DVT episode (in the first hours or days), the clot is hypoechoic, homogeneous, elastic and it dilates the vein. On the contrary, an older clot (several weeks) slowly becomes more heterogeneous, harder and smaller. The clot echogenicity actually depends on its blood cell composition, distribution and on its fibrin mesh [4]. The

incompressibility of the vein during the ultrasound test is considered as the main criterion of a DVT detection. Conversely, using the adjacent artery as a reference point, the full compression of the vein with a minimal deformation of the artery indicates an absence of thrombosis. Moreover, the vascular paresis (fixity of the venous valves) can indicate the presence of a blood clot as well.

2) Color Doppler imaging (CDI)

The DVT diagnosis is therefore primarily based on the B-mode 2-D imaging. CDI can also be useful since the velocity and the direction of the blood flow in the vessel are displayed on the ultrasound imaging. This is usually done with lower frequency ultrasound waves, so the resolution of the 2-D image is deteriorated. The absence of a flow in the vein means that there is a blood clot but the presence of a flow is not enough to rule out the possibility of a DVT. Indeed, a partial clot can be hidden because of the low resolution or can cause an accelerated flow.

3) Shear wave elastrography mode

We mention previously in paragraph II.B.1) that the blood clot hardness (and hence elasticity) depends on the clot age. The exact age of the thrombus can help determining the right treatment (anticoagulant, surgery). Several studies (*e.g.* [5] and [6]) create an animal model to estimate the exact age of the venous thrombus *in vivo* using ultrasound elastograhy. On human patients, the treatment efficiency makes the experiment more difficult. However, for some patients still presenting a DVT after three months, the results show a correlation between the shear wave velocity measures and the age of the thrombus [7]. Furthermore, a qualitative color map elastogram could give us information on the clot structure.

C. Acquisition system: Toshiba Aplio 500

In our project, we currently focus our research on ultrasonography and elastography because they seem to be promising to characterize the blood clot structures and emphasizing the existing links to the patients' physiopathologies. Moreover, 3 dimension (3-D) ultrasound imaging can also be a further way of exploration to analyze the blood clot structure. At Brest hospital, three systems are available to make these measures: (a) Toshiba Aplio 500[1], (b) Siemens Acuson S3000[2] and (c) Philips IU22[3]. To create our database, we use Toshiba's system since we can define an elliptical region of interest (area in which the shear wave velocity is estimated) around the vein and the quantitative measures of the shear wave velocity seem to be more

stable (*i.e.* it has lower standard deviations in similar measurement conditions).

Currently the available transducers for vascular imaging at Brest hospital do not enable us to make elastography imaging. For this reason, we choose an appropriated probe to observe the organs and their structures within the abdomen. Therefore, this probe allows us to use elastography imaging which greatly helps to diagnose a liver or a pancreas fibrosis. Our ultrasound echo signals are acquired using a convex array ultrasound transducer (Toshiba PVT-375BT). With a variable carrier frequency in 1.5 to 6 MHz, we can visualize the venous network on a depth of 0 to 10 cm.

In the Shear Wave Elastography (SWE) mode, three display modes are available on Toshiba's system (see Figure 1): (a) shear velocity named speed mode (m/s), (b) modulus of elasticity named elasticity mode (kPa) and (c) propagation mode. The shear velocity c_s (m/s) and modulus of elasticity E are [1]: $E \approx 3\rho c_s^2$ where ρ is the volume density (kg/m^3).

The speed or the elasticity modes provides a quantitative measure and a dynamic visual display of tissue stiffness. The propagation mode makes possible the observation of the shear wave propagation through the tissue in a single image. This mode is useful to determine the data reliability, see Figure 2. If the shear waves, lines, are parallel, the reliability in this area is high. In contrast, distorted and not paralleled shear waves correspond to a low reliability. One can also verify the reliability of the obtained data with the speed or elasticity mode. The system does not displayed color in areas with low reliability.
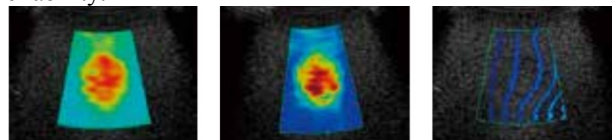
(a) Speed mode (m/s) (b) Elasticity mode (kPa) (c) Propagation mode

Figure 1: Three available display modes: shear wave velocity (speed mode), modulus of elasticity (elasticity mode) and propagation mode [8]
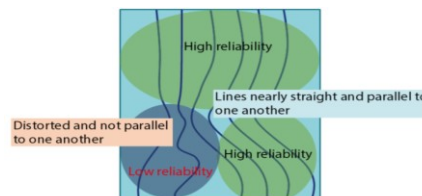

Figure 2: Reliability of the propagation display [8]

D. Data acquisition process

During the medical examination, the patient lies on his back. The medical expert begins by locating the blood clot head using compression ultrasonography. Then, he switches to the (SWE) mode and selects a region of interest (ROI). A part of the tissue is deformed by the shear wave. For an existing obstacle (such as a tumor in the tissue or a clot in a vein), the shear wave velocity in that area is different from their velocity in the surrounded velocity. A softer obstacle slows down the shear waves as opposed to a stiffer obstacle which makes them faster.

The system displays the SWE image on the left side of the screen and the ultrasound image on the right side, see Figure 3. The expert selects an area (an ellipse or another shape) around the blood clot on the ultrasound image. Then, the system returns the shear wave velocities in this area and displays the mean and the standard deviation values at the bottom of the screen, see Figure 3. After checking the data reliability, a screenshot is made and added to our database.

Moreover, we should mention that, for every patient, two experts make 10 measures each. The reason of this protocol is to reduce human errors during the examination (*e.g.* probe pressure on the skin, localization). For each patient, a second check-up is made three months later. In most cases, the treatment dissolves the blood clot but new measurements are performed again.

E. Data description

The image data acquired with Toshiba Aplio 500 are in a format named digital imaging and communication in medicine (DICOM). This is the standard for handling, storing, and transmitting medical imaging information and related data. A DICOM file object consists of a number of attributes (metadata such as name, age, etc.) and also one special attribute containing the image pixel data (ultrasound, X-rays, MRA, CTA, etc.).

In our case, the image data is a color screenshot as shown in Figure 3. This image contains different information: the acquisition parameters (system, probes, date), the patient's name (it is erased on the Figure 3 for medical secrecy), the ultrasound image, the elastography, the elliptical ROI selected by an expert and the shear wave velocity in this area. Raw images are not available with Toshiba's system. For this reason, we have to extract and process the ultrasound image and the elastography from the screenshot and make some preprocessing on them.

The metadata of the DICOM file give us information about the patient (name, age, gender), some acquisition parameters (e.g. probes, emitted frequency) and the images (size, depth). It is worth mentioning that in our data, the DICOM files do not contain any information about the shear wave velocity. This information has therefore to be recovered from the image data. Thus we decided to create a human computer interaction (HCI), which will be described in the next section.

III. DATA-READING, -CONVERSION AND - PREPARATION

The previous section describes the acquisition system. However, these data are exported in DICOM format, so the ultrasound image cannot be directly processed. In this section, we present our method to recover the shear wave velocity and the acquisition parameters from the screenshot, to extract and to prepare the ultrasound image for further simulations (e.g. using the scattering operator [1]).

A. Human computer interface description

Our application browses through all DICOM files in order to convert the file and to recover information unavailable in the metadata. Figure 4 illustrates the HCI.

Each DICOM file is displayed on the middle of the HCI (< 2 >). Right above the image, one can see the patient's number, the month (zero or three) and the image number (< 1 >). The user can indicate the presence of a blood clot (checkbox in < 3 >) and the location of the clot if he knows it. The comment of the medical expert (note 17. in Figure 3) is composed of his initials and the measure number which can be stored in the fields < 3 >.

The right part of the HCI is dedicated to the echography. The two checkboxes < 4 > have to be checked if the image contains an ultrasound part and an ellipse around the clot. The different fields of < 5 > correspond to the ultrasound parameters (notes 9. to 17. in Figure 3) and they will be useful to evaluate the impacts of these parameters on our future simulations.
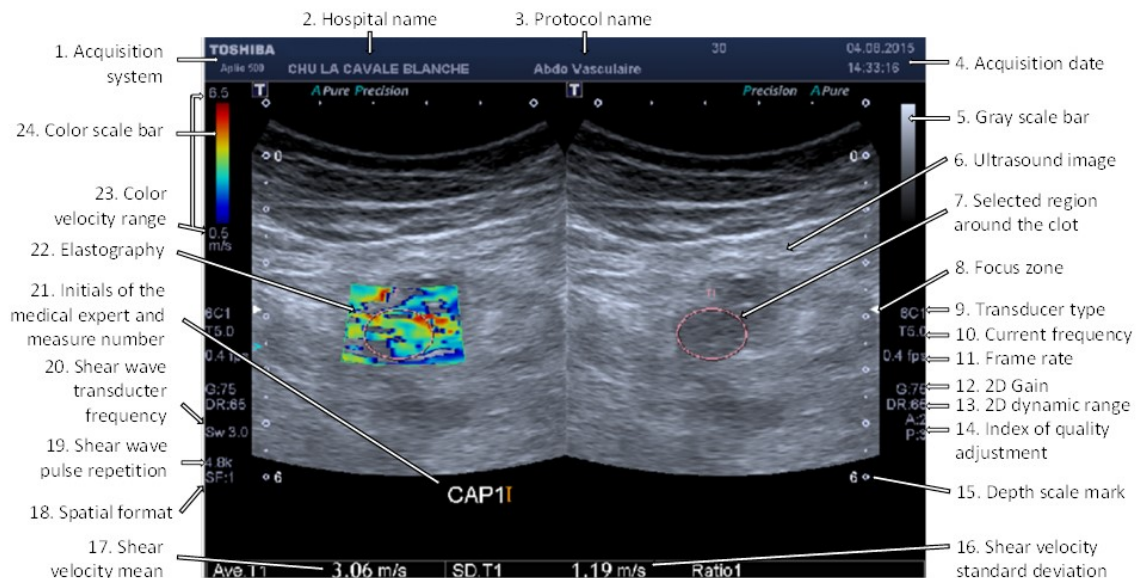

Figure 3: Screenshot taken with Toshiba's system and composed of the elastography and ultrasound images; the measurement parameters, the mean and the standard deviation of the shear wave velocity are displayed on the border of the image.
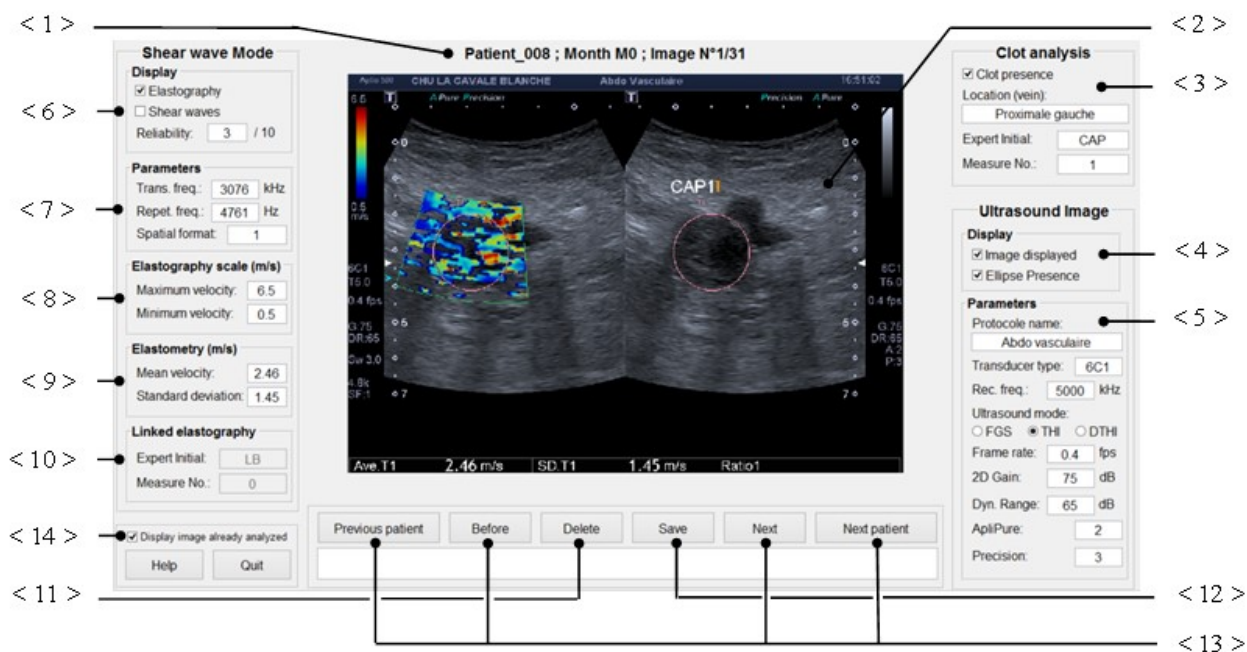
Figure 4:HCI of our application to manually extract information from the screenshot image.

The left part of the HCI is dedicated to the shear wave elastography mode. In the box < 6 >, the user can indicate if the image displays the elastography or the shear wave propagation (see Figure 1). He can also estimate the reliability of the acquisition. The shear wave parameters (notes 18., 19. and 20.) are entered fields < 7 >. The four next fields (< 8 > and < 9 >) allow the user to enter the color range (note 19. in Figure 3), the means (note 16.) and the standard deviation (note 15.) of the shear wave velocity.

Furthermore, the user can delete or save changes using the dedicated buttons (< 11 > or < 12 >). The image is then converted in the bitmap format ('.bmp'). The recovered information and the metadata are stored in a file. The navigation between the patient's DICOM files is made using the buttons 'Previous patient', 'Next patient', 'Before' and 'Next' (< 13 >). The already exported files can be skipped by checking the checkbox <14>.

B. Elastography and ultrasound image separation

Once the image has been converted in a bitmap format, the elastography part and the ultrasound part are still in the image. This paragraph explains how we isolate these two parts and how we estimate the depth resolution. This information is, in fact, not contained in the metadata so we use the depth scale marks (see tag 14. in Figure 3) to compute it. These marks have a special pixel color, so we segment the image on this color value. Some marks are not filled. After filling them, we make an erosion to remove the isolated pixels (pixel of the ultrasound image with the same color as the marks). Then, we calculate the middle mark indexes, count the number of mark and estimate the depth resolution. The ultrasound and elastography images are finally extracted so that no scale mark nor a black border is present on images. An example is shown in Figure 5.
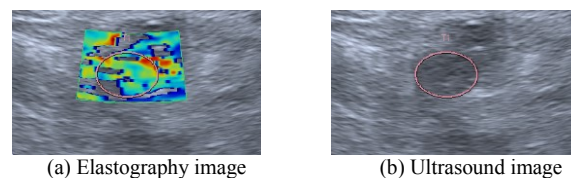

(a) Elastography image   (b) Ultrasound image

Figure 5: Elastography and ultrasound images extracted from the screenshot image illustrated in Fig. 1

C. Blood clot image extraction

One of our final project goals is to characterize the blood clot structure to identify the thrombosis triggering factors. To do so, we want to apply the scattering operator, based on wavelet transforms [9], to analyze the blood clot texture on the ultrasound images. However, we need to have images containing only the blood clot. To simplify and reduce the computing effort of the scattering operator, these extracted images should be squares and have a power of 2 size. The next paragraphs explain our strategy to create our database composed of blood clot resized square images.

1) Ellipse properties

To extract the biggest square image of the blood clot, we used the ellipse drawn by the medical expert. This ellipse has a special color that we use to create his mask. Therefore, we segment the image at this specific pixel color, then, we close its outline if necessary and we fill the shape (see Figure 6). Then, with the image processing Matlab toolbox, we get the following properties of the ellipse: centroid O, orientation α, major a and minor b axes.

(a) Global ultrasound image   (b) Segmentation

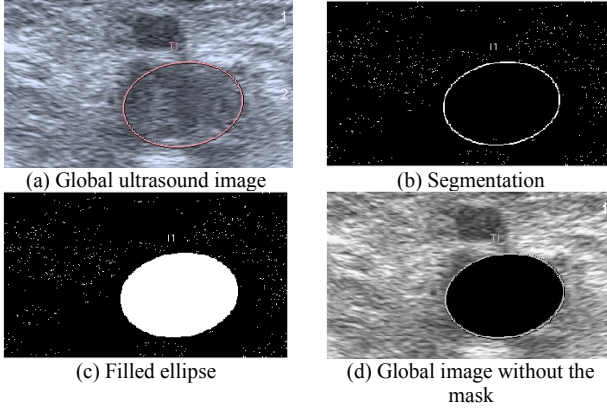(c) Filled ellipse   (d) Global image without the mask

Figure 6: Ellipse mask creation

2) Extraction of the biggest square image possible

The biggest square inside an ellipse is illustrated in Figure 7. Its width W, obtained using the ellipse equation, is the solution of the following equation:

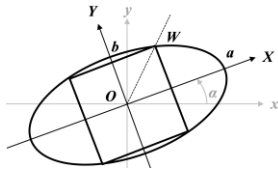$$\frac{W^2}{a^2} + \frac{W^2}{b^2} = 1 \qquad (1)$$

Figure 7: Extraction of the largest square inside an ellipse.

The square center and its size are by now known, but its orthonormal system and the one of the global image are not the same. They differ by an angle α, so, to extract this square image, the global image had to be rotated accordingly α. However, this rotation generates unintended artefacts as it can be seen in Figure 8.
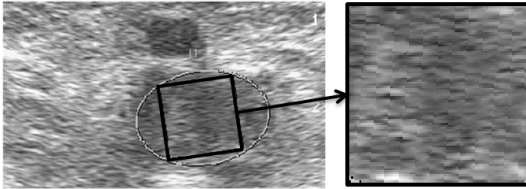

Figure 8: Extraction of the largest square inside an ellipse on an ultrasound image: the rotation distorts the image.

3) Extraction of the biggest square image possible without rotation

To avoid these artefacts, we decide to not rotate the global image and to find the biggest square in the image orthonormal system. Figure 9 and Figure 10 illustrate our idea, the different variables and the results without artefacts. The width c is computed using the following system:

$$\frac{X^2}{a^2} + \frac{Y^2}{b^2} = 1 \qquad (2)$$

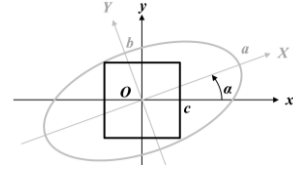where $X = c(cos\alpha - sin\alpha)$ and $Y = c(cos\alpha + sin\alpha)$.

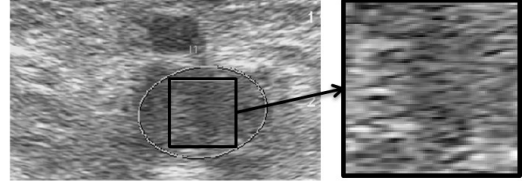Figure 9: Extraction of the largest square inside an oriented ellipse.

Figure 10: The extracted image is smaller with this second method but there is no artefact

4) Image resizing

The size of the square differs according to the patient (its anatomy), the clot age, its size and its localization (vein). To compare their scattering transform, we need to resize them so that they all have the same size. We make the simulation with two different sizes: 64x64 or 128x128 pixels. Moreover, we compare four resizing methods: nearest neighbor interpolation, bicubic interpolation and zero padding in the Fourier or in the cosine representation. These two last method means we compute the image transformation (Fourier or cosine), add zeros on the borders until the desired size is obtained and finally calculated the inverse transform. If the goal size is relatively close of the original size, these four methods give very similar results. When the goal size is more than twice the original, we can see some differences (see Figure 11). The bicubic interpolation seems to give better results.
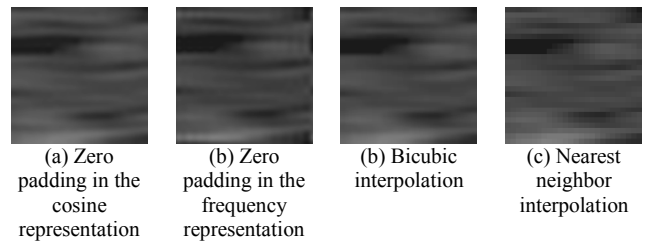

(a) Zero padding in the cosine representation   (b) Zero padding in the frequency representation   (b) Bicubic interpolation   (c) Nearest neighbor interpolation

Figure 11: Comparison among four methods to resized a 26x26 image on a 128x128 image

IV. PREPROCESSING

A. Contrast Problem

The previous section explained how to create our database of ultrasound images. We distinguish two kinds of images: (a) global images where we can see the blood clot, the artery and tissues and (b) the blood clot image. However, the images are not ready for simulation. As one can see in Figure 12, the contrast and the brightness can mostly differ between two patients. To standardize our database, we decided to equalize the histograms of the global images.
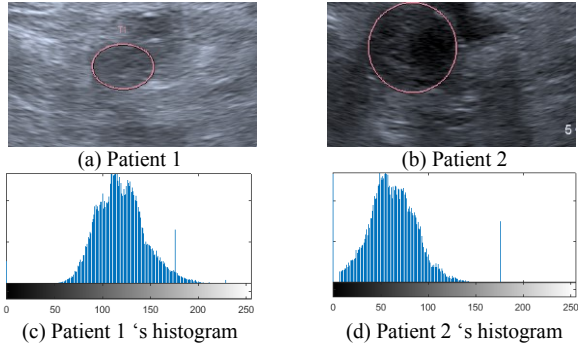
(a) Patient 1   (b) Patient 2

(c) Patient 1 's histogram   (d) Patient 2 's histogram

Figure 12: Images from two different patients and their histogram

B. Histogram equalization

Figure 13 shows both images of Figure 12 after the equalization of their histogram. The output images have now a similar contrast and brightness.
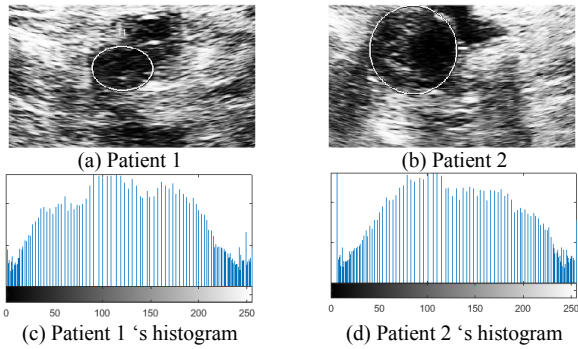

(a) Patient 1   (b) Patient 2

(c) Patient 1 's histogram   (d) Patient 2 's histogram

Figure 13: Images after histogram equalization and their histogram

V. CONCLUSION

DVT is a common, serious and multifactorial disease. Our final objective is to determine the DVT causes by characterizing the blood clot structure. Several techniques exist to analyze their structure: phlebography, MRA, CTA ultrasonography. Ultrasound and elastography imaging have the advantage to be easy, repeatable, cheaper and non-invasive. Toshiba's system allows us to make this kind of imaging but also to measure the shear wave velocity (quantitative elastography) in a region of interest. This measurement is currently not in the metadata of the DICOM file. Moreover, we cannot export the raw data with this system, so we are dealing with screenshot images. This paper describes the database creation and the preprocessing applied on such images. Indeed, we want to compute the scattering operator and statistical methods to characterize the blood clot texture. Our next simulation will compare the results obtained with different image sizes, resizing methods and with or without histogram equalization.

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