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A new method to determine arterial distensibility in small arteries

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***Abstract*—Several methods allow to measure arterial distensibilty. One of them consists in estimating the direct distensibility (D) from diameter and distending blood pressure. Herein, we propose a new method to assess the distensibility in small arteries which is based on spectral analysis of time motion mode ultrasound images of radial arteries. A Fourier transform was performed on intensity of upper and lower walls. Spectral amplitude at heart frequency from both wall spectra was estimated and summed (SumAmp). SumAmp was then compared with direct distensibility. A significant correlation was found between SumAmp and D (r = 0.7, p = 0.02).**

I. INTRODUCTION

Numerous studies have shown that arterial distensibility which is the reciprocal of arterial stiffness, represents a relevant and surrogate marker of cardiovascular events [1]-[2]. Arterial distensibility reflects functional properties of arterial wall and allows the detection of vascular changes related to vascular disease. Several techniques - more or less basic - have been developed to evaluate the arterial distensibility [3]. Among them, three are noninvasive: 1) pulse transit time calculation, 2) analysis of the pulse pressure wave contour, and 3) direct distensibility estimation using measurements of diameter and distending blood pressure. Some of these techniques can be more or less accurate and reproducible [3].

For the method of pulse transit time which allows an assessment of regional arterial stiffness, the pulse wave velocity is recorded on two arterial segments. To estimate the arterial stiffness, the distance on the skin between both recording sites is needed. However, this distance is very often evaluated approximately which entails a nonaccurate measurement of arterial stiffness. Moreover, for a device as the tonometer, a pressure is applied with a probe on the site of interest to record the pulse wave velocity in the arterial segment. Therefore, the estimation of arterial stiffness can be influenced by this pressure.

Devices which allow a more accurate estimation of the distensibility are the ultrasound devices [4] or magnetic resonance imaging (MRI) systems [5]-[6]. Ultrasound images and MRI allow the direct measurement of the diameter. By combining diameters estimation with a blood pressure measurement, arterial distensibility can be assessed. Ultrasound images can be recorded in different modes: B-mode or time motion mode (M-mode) [7]. There are also some features as echotracking which track the arterial wall. On M-mode ultrasound images, the motion of arterial structures can be recorded over several seconds. Thus diameter changes can be measured on several cardiac cycles to estimate arterial distensibility.

Arterial distensibility is often combined with a measurement of intima-media thickness (IMT) to evaluate atherosclerosis [8]. When an artery distends its wall, some deformations appear on the wall but also on the surrounding layers. However, neighboring tissues of the artery wall are usually not taken into account to assess the arterial distensibility. We suggest that surrounding layers have probably an influence on the arterial distensibility. If surrounding layers are rigid, the artery could probably distend its walls less. Therefore, it could be interesting to analyze these layers to provide more accurate distensibility estimation.

To study the surrounding layers, we propose to use a spectral analysis. We suggest that, the more an artery is able to distend its wall (deformation), the higher the energy necessary to realize this action. Therefore, a spectral analysis of the wall will show a higher spectral amplitude for an artery with a high distensibilty compared to an artery with a low distensibility. We herein test this hypothesis by performing a spectral analysis of M-Mode ultrasound images of radial arteries. In this present work, the spectral method has only been applied on the upper and lower arterial walls to confirm our hypothesis. From our knowledge, arterial distensibility has not been determined yet with a spectral analysis of intensity lines from M-mode images.

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I. MATERIALS AND METHODS

A. *Population*

Ten healthy subjects (3 males, average age: 46 ± 13 years) participated in the study. None of them had a history or were treated for hypertension, diabetes mellitus, or showed any evidence of disease at the time of the study.

B. *Instrumentation*

For the measurements, subjects were supine in a quiet room. Ultrasound technique being highly sensitive to motion artifacts, subjects were asked to refrain from moving during the acquisitions. Moreover, the arm of subjects was immobilized and acquisitions were short enough to avoid motion artifacts on images. Brachial blood pressure was measured with an automatic blood pressure monitor (WelchAllyn, USA), just before the ultrasound image acquisitions. Ultrasound images of radial arteries were recorded with a Dermcup device (Atys Medical, France). This device allows acquisitions in real-time of *in-vivo* skin vertical cross sections: 16 mm x 12 mm. A 25 MHz transducer was used to record images with a high resolution and all our images have been recorded by the same operator. Ultrasound images were acquired in M-mode. This mode represents the temporal changes in echoes and allows to record motion of the interfaces. The depth of echo-producing interfaces is displayed along vertical axis and time is displayed along the horizontal axis (see an example in Fig. 1). Our recorded images have a depth between 6-9 mm and last 4 seconds. The size of the image matrix is 319x799 pixels (319 horizontal lines and 799 vertical lines).

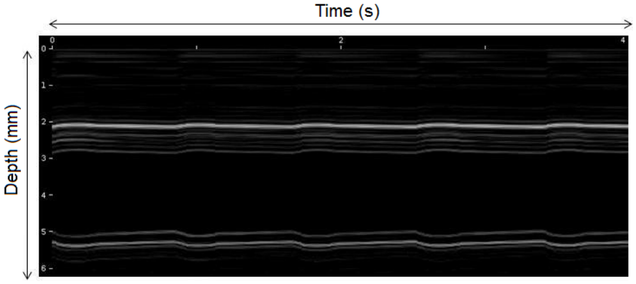

Figure 1. M-mode ultrasound image of radial artery.

C. *Direct assessment of radial distensibility*

During cardiac cycle, arteries change their diameter. It increases during the systole, when the heart ejects blood into the arterial network, and decreases to a baseline value during the diastole when the heart relaxes. These diameter changes can be observed on our M-mode ultrasound images. They correspond to the periodic wall deformations visible on Fig. 1. By tracking the arterial walls motion, the distensibility can be directly estimated.

For this purpose, radial images have first been normalized in gray scale (0: black - 255: white). Then, to better detect the lumen of the artery, we computed a thresholding operation with the Otsu method on the image. This method allows the optimal threshold for an image to be found automatically [9].

From the first column (first vertical line) of the image matrix we plot the profile of the artery which allows the detection of the lumen borders (see Fig. 2).

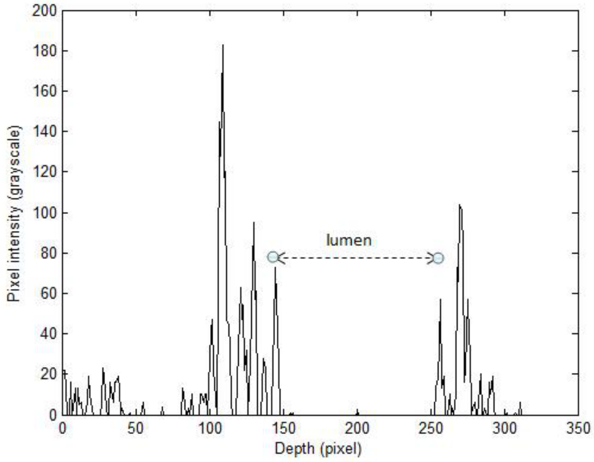

Figure 2. Artery profile to detect lumen borders.

Thus two pixels are located, one which corresponds to the beginning of the upper wall and another to the beginning of the lower wall. The intensity of these pixels is then compared with the intensity of neighboring pixels of the next matrix column. In this next matrix column, pixels from the same line, from the five upper lines and from the five lower lines are checked. We then kept the pixel which has the closest intensity to the pixel from the previous matrix column. By iteration of this process, we are able to track the motion of the wall artery.

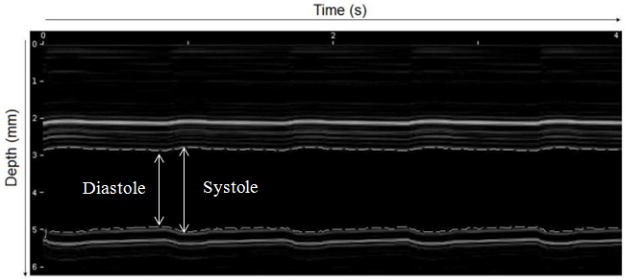

Figure 3. Traces of upper and lower walls (highlight in dotted line) to estimate arterial distensibility.

From the track of upper and lower walls (Fig. 3), we estimate systolic and diastolic diameters which are respectively the mean maximum and minimum distances between the traces (mean estimated from systolic and diastolic diameters of all cardiac cycles recorded on the image).

Radial distensibility can then be calculated as follow:

$$D = \frac{D_{sys}^2 - D_{dias}^2}{D_{dias}^2 \cdot PP_{brachial}}$$

where *Dsys* and *Ddias* represent the systolic and diastolic diameter, respectively and *PPbrachial* represents the pulse pressure in brachial artery which corresponds to the difference between the systolic and diastolic blood pressure. We propose to estimate the arterial distensibility by a spectral analysis of walls and to compare the results with the direct method.

D. Spectral analysis

Upper and lower walls have a thickness of several pixels. Therefore, walls have been isolated into two intervals of 10 pixels each as shown with dotted lines in Fig. 4.

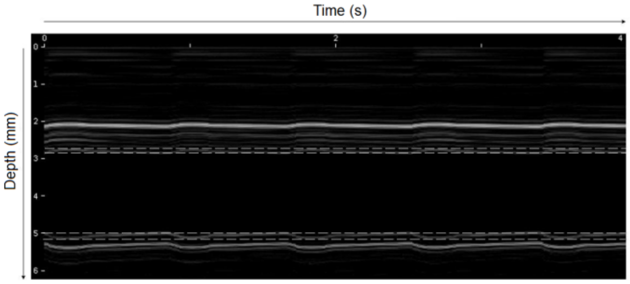

Figure 4. M-mode ultrasound image where dotted lines represent isolated upper and lower walls.

These intervals are then cut into six overlapping intervals of five pixels in order to be closer to the wall. On each of the six intervals, the mean of the pixels intensity is calculated. We can note that intensity variations have a temporal periodicity (see Fig. 5).

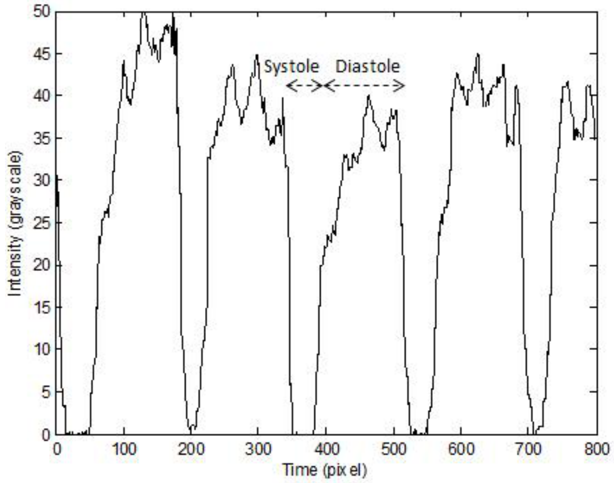

Figure 5. Intensity variations of pixels from lower wall of a radial artery.

A Fourier transform of the six average lines of intensities is then computed. Spectral amplitudes at heart frequency from spectra of upper and lower walls are estimated. Among the six Fourier transforms obtained, we retain only the one which has the highest amplitudes at the heart frequency (see Fig. 6). The spike visible at the highest frequency corresponds to the sampling frequency: 200 Hz.

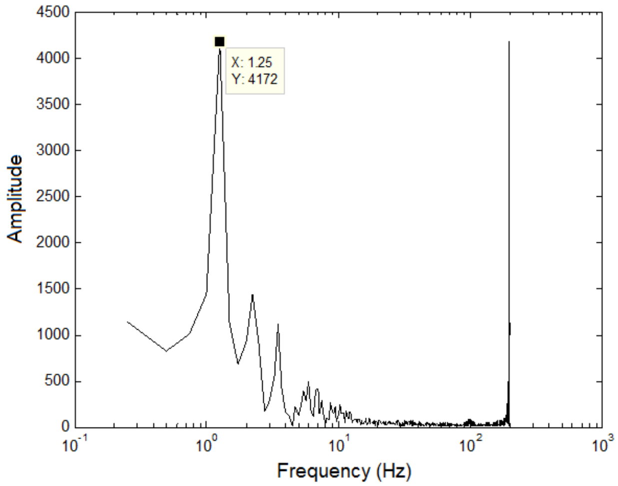

Figure 6. Example of spectral amplitude from upper wall of a radial artery.

The sum of spectral amplitudes form upper and lower walls at heart frequency is then calculated. Finally, the relationship between this sum and the direct distensibility measurement is evaluated with a statistical test.

The different steps of our processing are summarized on Fig. 7.

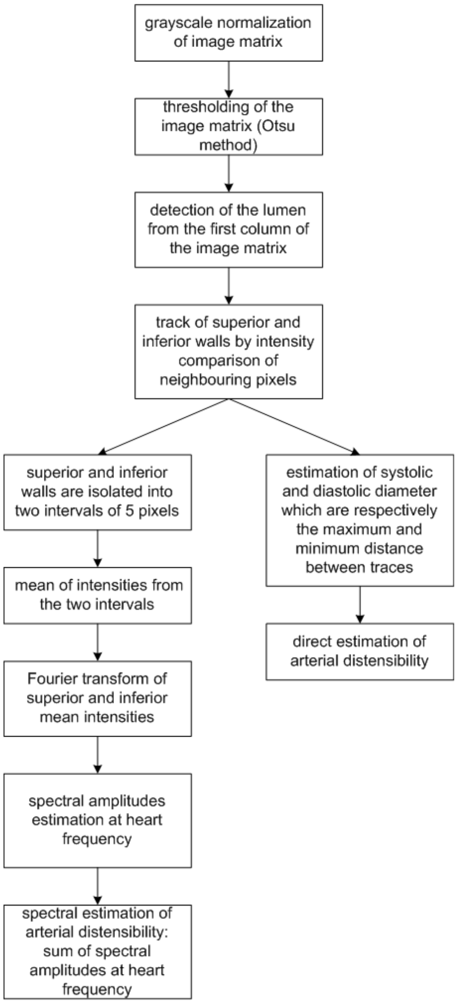

Figure 7. Diagram which summarized the processing.

E. Data analysis

Statistical tests are performed with Tanagra software [10]. A Spearman correlation test is used to test the relation between spectral and direct distensibility estimations. To compare spectral amplitude from upper wall with the one of lower wall the Wilcoxon signed-rank test is used. Tests are considered as significant when $p < 0.05$.

II. Results and Discussion

M-mode ultrasound measurements allow to record wall motion on several cardiac cycles but also the deformations in surrounding layers of arterial wall.

A significant positive correlation is found between direct and spectral methods of distensibility assessment ($r = 0.70$, $p = 0.02$), see Fig. 8. The higher the direct distensibility measurement, the higher the sum of the spectral amplitudes at heart frequency.

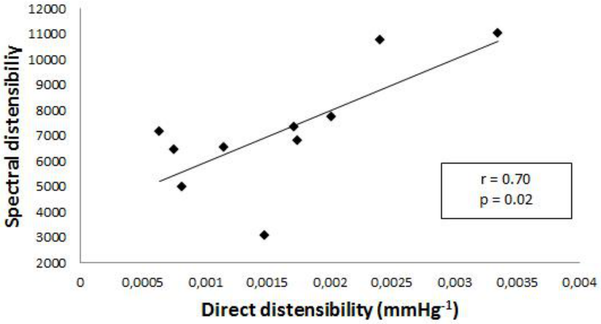

Figure 8. Relation between direct distensibility and spectral measurements of radial distensibility.

Spectral amplitudes have been evaluated at heart frequency because cardiac activity has a major role in the cardiovascular system and can be easily observed. According to the American Heart Association, the average resting heart rate is 60-80 beats per minute (i.e. 1-1.33 Hz). Our spectral analysis of arterial wall is well correlated with the direct assessment of distensibility. Thus, this method could be applied to analyze surrounding layers. The study of the deformations transmission into the tissues nearby the walls could probably improve the arterial distensibility estimation. If the neighboring tissues are soft, which can be shown by an important transmission of the deformations, the artery would probably distend its wall more.

Several studies have shown that age and pathologies as diabetes decrease the arterial distensibility [11]. These factors may probably have an impact on the structure of surrounding layers of arterial wall. Combining deformations of surrounding layers with distensibility measurement may probably contribute to improving the comprehension of vascular diseases.

We also note that average spectral amplitude of our ten subjects is higher for lower wall than for upper wall. The difference is not significant (4434 ± 2565 *vs* 2761 ± 1100, $p = 0.13$, Wilcoxon signed rank test) however, this result shows that upper and lower walls are not strictly symmetric.

During the acquisition of ultrasound images there is already a transducer on the arterial segment. Therefore, the continuous measurement of the pressure in the radial artery is not possible. Thus, brachial pulse pressure was used to calculate radial distensibility. However, pressures in radial and in brachial arteries are different. A measurement of pressure in the radial artery could give a more accurate estimation of radial distensibility and could slightly change the correlation between direct and spectral methods of distensibility assessment.

Moreover, the size of the population is small. This work could be carried out on a larger population but our preliminary results are encouraging.

III. Conclusion and Perspective

A significant correlation was found between spectral and direct methods of the radial distensibility assessment. Moreover, the spectral method provides additional information about artery behavior as the symmetry or asymmetry of upper and lower arterial walls. For future work, the spectral method could be applied on wall surrounding layers to analyze the deformation propagation and improve the estimation of arterial distensibility.

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