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Approximate Measurement of Brachial Artery (BA) Diameter with Response to Flow Mediated Dilation (FMD) Through Image Analysis Method from MATLAB Computation

Zabariah Zakaria, Hisham Mohamad Desa, Siti Afifah Mohshim, Naszariah Mohd Noor

Abstract— The analysis for the trend of change for diameter of the brachial artery (BA) during baseline (normal relax) condition and flow mediated dilation (FMD) response by using MATLAB software. Data and image (using ultrasonography technique) of BA diameter are taken from three healthy subjects. Results of the analysis reveal that after the release of blood flow blockage the trend for BA diameter change is rapid increase followed by gradual decrease due to FMD reactive response. The trend of BA diameter change as measured by the sonographer is more variable and the pattern of reactive hyperaemia response is less obvious when compared to the results from MATLAB computation. This shows that computation method (using MATLAB algorithm) produces more smooth BA diameter change and obvious reactive response when compared to the measurement by the sonographer indicating that MATLAB computation produces better accuracy than manual estimation by the sonographer. The main objective to employ and experience the learning process of performing essential image processing has been achieved.

Index Terms— brachial artery (BA), reactive hyperaemia, flow mediated dilation (FMD), diameter, MATLAB algorithm, sonographer, accuracy

1 INTRODUCTION

The method using flow mediated dilation (FMD) describes the increase in diameter of a blood vessel, generally the brachial artery (BA), in response to a sharp increase in the shear stress associated to increase of blood flow [1]. The shear stress stimulus provokes the endothelium to release nitric oxide (NO) with subsequent vasodilation that can be imaged then quantized as an index of vasomotor function. This technique is attractive because it is non invasive and allows repeated measurements [2].

The reaction of the arterial diameter to the change of blood flow can be measured non-invasively by means of ultrasound, after an ischemia caused by a temporary forearm occlusion. The dilation magnitude, expressed as the percentage change of the dilation diameter after 60 seconds of having liberated the occlusion in the basal diameter (FMD %), is traditionally used to evaluate endothelium response. The conventional protocol assumes that it is around this time that maximum dilation takes place. Diameter measurements are carried out manually from a still image using the available cursors in the ultrasound equipment. The process involves wall to wall manual tracking of the BA diameter often requiring experienced sonographer. The technique revealed to have important methodological deficiencies and their use is discouraged [1].

We proposed to apply image analysis technique and use computation method to estimate the diameter of the BA from recorded BA ultrasound images. Moreover, the method will become a platform to employ and experience learning process of essential image processing technique. The technique is expected to be non-user dependent as it relies mostly on automatic calculation of the diameter by software programming. Thus, the element of experienced or expert sonographer dependence can be eliminated.

2 METHOD

BA images from three subjects, who participated in a study of endothelial function which comprised students of Universiti Kebangsaan Malaysia (UKM), members or relatives of Hospital UKM staff, and people from the local community, were selected for analysis. The selected subjects are healthy individuals who are free from major cardiovascular disease risk factors (cigarette, smoking and hypertension) [3]. Numerous factors affect flow-mediated vascular reactivity, including temperature, food, drugs and sympathetic stimuli, among others [2].

2.1 Imaging Equipment

The ultrasound system Sonos 5000 ultrasound equipment from Hewlett Packard, Inc. (Fig. 1) was used to record the images of the BA during baseline (normal relax) condition and FMD response. After taking three baseline images, an inflatable cuff is wrapped around the upper arm as shown in Fig. 2 (a), to induce shear stress stimulus for FMD reaction.

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Fig. 1: Ultrasound system utilized for measuring diameter of the BA and recording the BA images

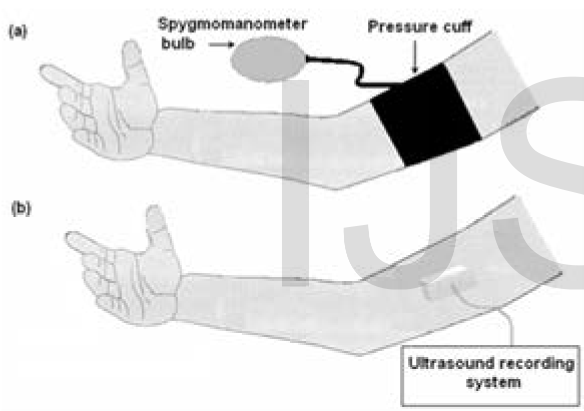

Fig. 2: Placement for (a) cuff pressure and (b) ultrasound probes for measuring the BA diameter and capturing images of the BA

The stimulus for FMD comprises of a four minutes blood flow blockage above the person's systolic blood pressure [3]. The ultrasound system has a linear array transducer able to emit frequency of 7.5 MHz and is attached to a high-quality mainframe ultrasound system that is able to acquire images with sufficient resolution for subsequent analysis [2]. The ultrasound probe was placed at few centimeters above the right elbow, proximal to the applied cuff pressure for flow blockage.

The baseline BA diameter was measured from the longitudinal image of the artery using a manual wall tracking technique. Color Doppler ultrasound imaging was used to improve measurement accuracy [3]. Measurements of BA taken by the sonographer are used as the true measurements which are used as the reference values.

2.2 Image Acquisition

The subject is positioned supine with the arm in a comfortable position for imaging the BA (Fig. 2b). The BA is imaged above the antecubital fossa in the longitudinal plane [3] and its diameter is measured during three conditions; baseline (after at least 10 minutes supine rest), during reactive hyperaemia (induced by inflation to 50mmHg above the subject's systolic blood pressure and then rapid deflation of the sphygmomanometer) [4].

Studies have shown that flow stimulation can variably used either upper arm or forearm cuff occlusion, and there is no consensus as to which technique provides more accurate or precise information. When the cuff is placed on the upper part of the arm, reactive hyperaemia typically elicits a greater percent change in diameter compared with that produced by the placement of the cuff on the forearm [2]. This may be due to a greater flow stimulus resulting from recruitment of more resistance vessels or possibly to direct effects of ischemia on the brachial artery. However, upper-arm occlusion is technically more challenging for accurate data acquisition as the image is distorted by collapse of the brachial artery and shift in soft tissue [2].

The sonographer measures the BA diameter through online manual wall tracking method applied to the captured image one by one. As soon as the diameter is obtained for a particular image, the image is then saved. Each subject has a number of BA images where the first three images are the baseline images and the fourth until end of file contain BA images after release of blockage having the FMD response.

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2.3 Image Processing using MATLAB R2009a

The BA images captured using the ultrasound system have been segmented. The image of BA to be segmented differs greatly in contrast from the background image. Changes in contrast can be detected by operators that calculate the gradient of an image. The gradient image can be calculated and a threshold can be applied to create a binary mask containing the segmented cell. First, 'edge' and the Sobel operators are used to calculate for the initial threshold value. The threshold is then further tuned by using 'edge' again to obtain a binary mask that contains the segmented cell [5].

The binary gradient mask shows lines of high contrast in the image. These lines do not quite delineate the outline of the object of interest. These linear gaps will disappear if the Sobel image is dilated using linear structuring elements, which can be created with the 'strel' function.

The binary gradient mask is dilated using the vertical structuring element followed by the horizontal structuring element. The 'imdilate' function dilates the image. The dilated gradient mask shows the outline of the cell quite nicely, but there are still holes in the interior of the cell. To fill these holes the 'imfill' function is used.

Then, the cell of interest has been successfully segmented, but it is not the only object that has been found. Any objects

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that are connected to the border of the image can be removed using the 'imclearborder' function. The connectivity in the 'imclearborder' function is set to 4 to remove diagonal connections. After that, in order to make the segmented object look natural, the object is smoothened by eroding the image twice with a diamond structuring element. The diamond structuring element is created using the 'strel' function. Next, each of the segmented images and the average of the segmented images will be calculated. Finally the results of diameter measurement for a subject's BA images, which includes a sequence of BA diameter change, are plot in a time graph. The graph is then compared to that obtained from the measurement by the sonographer.

3 RESULTS AND DISCUSSION

Fig. 3 shows an example of the original BA image of a subject with three lines; red, yellow and blue that are used to calculate the diameter of BA. After the application of diamond structuring element to the original BA image, the BA image is then converted to black and white as shown in Fig. 4. The diameters at each of the three colored lines obtained from the black and white image are then averaged. The process of measurement is repeated for each frame of the BA images.

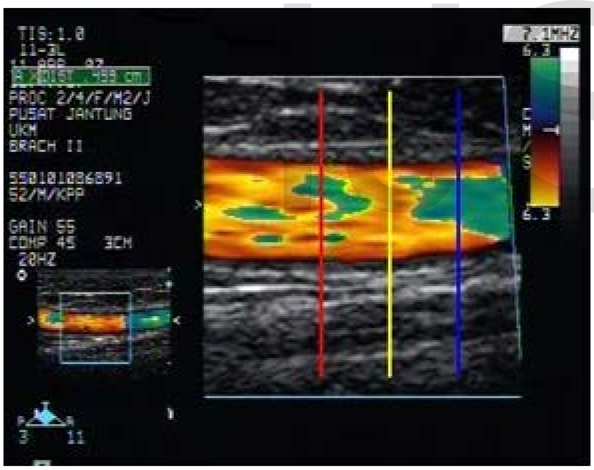

Fig. 3: Original image of BA with three lines; red, yellow and blue

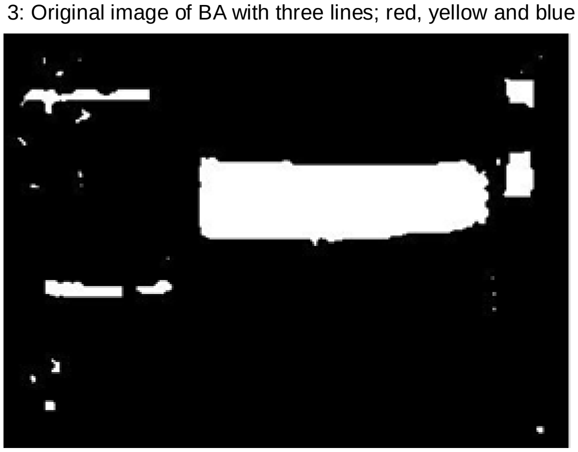

Fig. 4: The BA image after using diamond structuring element

The average measurement of series of the BA diameters is plot on a graph by implementing Microsoft Excel as shown in Fig. 5. The graph shows the trend of BA diameter changes for the three selected subjects measured by sonographer and MATLAB algorithm during baseline (frame 1 to 3) and during reactive hyperaemia (frame 4 and above). From Figure 5, it can be seen that MATLAB algorithm establishes a consistent measurement of the BA diameters for all three subjects. It is also shown that after baseline condition and after the release of blood flow blockage (hyperaemia) during the reactive FMD response, the BA diameter increases rapidly in few frames above the baseline condition followed by slow decrease towards the baseline for the remaining frames. In the graph of BA diameters measured by the sonographer, the trend of BA diameter change fluctuated after frame 3, which is during the reactive hyperaemia response. This shows that there is high variation of BA diameter measurement from the BA images in almost all frames as measured by the sonographer.

The results from MATLAB algorithm obtained in this analysis also show obvious trend of reactive hyperaemia response which consists of rapid increase followed by slow decrease of the BA diameter in similar manner as found in the previous study [3]. However, the trend of BA diameter change as measured by the sonographer is not as obvious as that obtained through MATLAB algorithm. This may be due to the main disadvantage of the procedures of FMD BA diameter measurement which requires the sonographer to do quick online manual wall tracking to obtain the BA diameter instantaneously for each frames of the ultrasound image captured during the reactive hyperaemia response. The procedure of measurement by the sonographer has the tendency to have high measurement errors. The errors may include irregularities of BA diameter and inconsistent measurement that produced small values of measured BA diameters. These small diameters in all frames as measured by the sonographer may be due to inaccuracies of edge detections by human eye (the sonographer). As for the MATLAB algorithm, the edge detection is definite due to sharp and concise separation between black and white regions of the processed images.

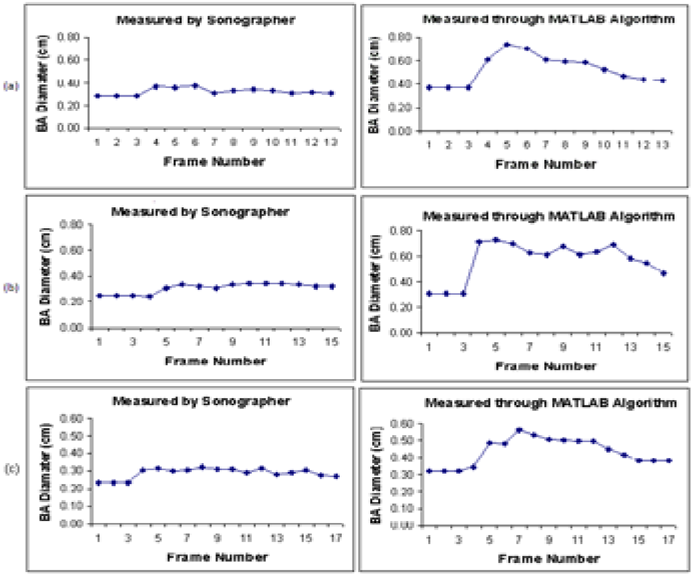

Fig. 5: BA diameter measured by sonographer and MATLAB algorithm respectively for (a) Subject 1, (b) Subject 2 and (c) Subject 3

4 Conclusion

Further algorithm refinement is required to strengthen the analysis of BA diameter change during the reactive FMD response. Tests on method repeatability and reproducibility are also required to justify the accuracy of the technique. Nevertheless, the main objective of the study to employ and experience the learning process of performing essential image processing has been achieved. The study also has shown that MATLAB algorithm for image analysis has yielded promising results which may be used alternatively rather than relying on the online measurement procedures conducted by the sonographer.

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Z. Zakaria was born in Seremban, Negeri Sembilan. She graduated with B.Sc. in Applied Physics (Medical Physics) in 2005 and obtained M.Sc in Medical Physics in 2006 from Universiti Sains Malaysia. She is currently a Lecturer at Universiti Kuala Lumpur British Malaysian Institute. Her main research interest is medical physics. This includes the medical radiation, radiation protection and medical imaging.

H. Mohamad Desa received the degree B.Eng. in Electrical & Electronics Engineering from Universiti of Hertfordshire (UK) in 1998 and M.Sc in Information & Mathematic Application from Universiti of La Rochelle, France (Image & Calculation) in 2007. He is currently a lecturer at Universiti Kuala Lumpur British Malaysian Institute. His research interests are electronics & biomedical engineering, instrumentation and image processing.

S. A. Mohshim received the degree B.Sc. in Applied Physics (Medical Physics) from Universiti Sains Malaysia in 2005 and M.Sc in Medical Physics from Universiti Sains Malaysia in 2006. She is currently a Lecturer at Universiti Kuala Lumpur British Malaysian Institute. Her main research interest is medical physics. This includes the medical radiation, radiation protection and medical imaging.

N. M. Noor received the degree B.Eng. in Electrical Engineering from Universiti Teknologi MARA in 2005. She is now currently a Lecturer at Universiti Kuala Lumpur British Malaysian Institute. Her main research interest is biomedical engineering. This includes the biomedical signal processing, instrumentation, imaging and informatics.