Detecting the Process of Blood Coagulation and Clot Formation with High Frequency Ultrasound

Chih-Chung Huang[1] Po-Hsiang Tsui[1,2] Shyh-Hau Wang[1,*] Chun-Yi Chiu[1]

[1]Department of Biomedical Engineering, Chung Yuan Christian University, Chung Li, Taiwan, 320 ROC
[2]Department of Biomedical Engineering, Yuan Pei Institute of Science and Technology, Hsin Chu, Taiwan, 300 ROC

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Abstract

High frequency ultrasounds, up to 50 MHz, were applied to assess changes of blood properties during coagulating and clotting. Experiments were performed using calcium chloride solution to induce the blood coagulation (BC) and clot formation (CF) in porcine whole blood of various hematocrits ranged from 25 to 55 %. The ultrasonic signals backscattered from the whole blood were digitized at a 500 MHz sampling frequency and collected for 30 minutes at one A-line per second temporal resolution. The corresponding M-mode images and integrated backscatters acquired from four transducers of different frequencies were processed to characterize blood properties. Two parameters, denoted as S_r and t_c respectively in response to the rate of change and duration between the onset of blood coagulation and the end of clot formation, were derived from the integrated backscatter as a function of time to further evaluate the sensitivity and accuracy for measurements. Results showed that backscattered signals acquired from different frequencies and their relative analysis may be applied to effectively detect the process of BC and CF. In particular, measurements using high frequency ultrasound tended to exhibits a better sensitivity to detect the coagulation, with larger average S_r and shorter t_c respectively corresponding to 0.23 dB/sec and 756 seconds measured from a hematocrit of 35 % using a 50 MHz transducer. The discrepancy between results of t_c measured by different frequencies may be readily associated with the resultant size of the resolution cell of the transducer and the pulse duration. Both ultrasonic M-mode image and integrated backscatter in this study were validated to monitor the process of BC and CF and specifically with those quantitative parameters, S_r and t_c. It enables a potential to further apply high frequency ultrasounds for early detecting BC and CF in clinical diagnoses.

Keywords: Blood coagulation, Clot formation, High frequency ultrasound.

Introduction

The blood clot is a meshwork of fibrin fibers running in all directions that composed of a part of blood cells and entrapped plasma. Normally the formation of clot provides a protective mechanism to stop bleeding from a wounded tissue. However, an abnormal clot, called thrombus, could be developed and attached inside the vessel wall. As there is an adequate force of blood flow exerting the thrombus, it could be come off from the attachment site to form an embolus and to flow in a blood vessel [1]. The emboli developed in a large artery or the left heart is severely hazardous for that it could flow downstream into peripheral vessels to further occlude blood supply in arteries or arterioles such as the brain, kidneys, or other vital organs [1]. A vulnerable embolus originated in the venous system or in the right heart could subsequently flow into vessels in the lung leading to such a dreadful syndrome as the pulmonary arterial embolism [2]. In addition, those immobile patients confined to bed frequently suffer from the formation of the intravascular clot corresponding to the obstructed flowing blood in any vessel for a few hours. Consequently, it is crucial to develop techniques capable of detecting the process of the blood coagulation and clot formation in blood vessels for early diagnosing the formation of any embolism.

To date, the simplest method to qualitatively characterize the process of BC and CF is to withdraw a certain amount of blood that is subsequently placed in a testing tube for observing and recording the transient time of BC and CF [3]. Further typical modalities developed to quantitatively detect the BC are based on three of the following principles: mechanical impedance, electromagnetism, and photometry [4]. Most of these modalities however are not appropriate for continuous and dynamic monitoring of the changes of blood properties as well as remain invasive sampling of the blood. Other feasibility studies by ultrasound techniques were carried out due to low cost and real-time capability with the involved ultrasound technique. Jacobs *et al*. [5] utilized two frequency

* Corresponding author: Shyh-Hau Wang
Tel: +886-3-2654504; Fax: +886-3-2654599
E-mail: shyhhau@cycu.edu.tw