Imaging of Cross-Sectional Elasticity for Diagnosis of Atherosclerosis

Hiroshi Kanai
Department of Electronic Engineering, Graduate School of Engineering, Tohoku University

Knowledge of the physical properties of atherosclerotic plaque is essential when evaluating its vulnerability in a clinical setting. Such knowledge, however, is still difficult to obtain with the various approaches developed to date. We present a noninvasive method for evaluating the regional elasticity (the elastic modulus in the circumferential direction) of tissue surrounding atherosclerotic plaque in which a novel *phased tracking method* is applied to measure minute changes in thickness of each of the multiple layers of the arterial wall during one heartbeat. By comparing the pathological findings with the distribution of elasticity, average elasticity of lipid and that of a mixture of smooth muscle and collagen fiber can be determined. Based on these reference parameters, each point is statistically categorized as lipid, mixture, or other. Thus, the plaque is *electronically stained* using transcutaneous ultrasound. By applying the method to the common carotid arteries (CCAs), the presence of thin collagen fiber was clarified along the arterial axis for normal subjects, while soft inclusion of lipid was found for every plaque in subjects with hyperlipidemia. This novel method offers potential as a diagnostic technique for detection of plaque vulnerability with high spatial resolution.

Keywords:

Vulnerability of Atherosclerotic Plaque: The normal artery has three distinct layers: the intima, the media, and the adventitia. During the initiation of atherosclerosis, LDL cholesterol accumulates in the subendothelial space within the arterial wall. Local vascular cells mildly oxidize LDL, which stimulates recruitment of monocytes and eventual deposition of macrophages. This process results in the lesion of atherosclerosis, the fatty streak. Vulnerable plaque typically has a thinner fibrous cap. Once a plaque has ruptured, the severity of the cardiovascular event (unstable angina, myocardial infarction, cerebrovascular disease, or sudden cardiac death.) is influenced by the extent of thrombosis. Stable plaque has a thicker fibrous cap protecting the lipid core from contact with the blood.

Elasticity: The quality that the arterial wall being able to stretch and return to its original size and shape.

For Measurement of Change in Thickness of the Arterial Wall: An ultrasonic beam was sequentially scanned at M (=60) positions with a linear-type ultrasonic probe of 7 MHz using conventional ultrasound diagnostic equipment, and multiple (N_m+1) points were preset from the luminal surface to the adventitia along the m-th ultrasonic beam (m=1,…, M) with constant intervals of h_0=375 μm at a time t_0 just before the ejection period. By dividing the

arterial wall into multiple layers, we defined the n-th layer (n=1,…,N_m) as being between two contiguous points, n and n+1, along each beam. For measurement of change in thickness of each of the N_m layers, the instantaneous depth $x_{m,n}(t)$ of the n-th point along the m-th beam was simultaneously tracked by applying the *phased tracking method* to the received ultrasound. The minute decrease of several tenths of a micrometer in wall thickness of the n-th layer resulting from the arrival of the pressure wave at the beginning of the ejection period was determined by $\Delta h_{m,n}(t)=x_{m,n+1}(t)-x_{m,n}(t)-h_0$.

Phased Tracking Method: In a newly developed *phased tracking method*, for calculation of the auto-correlation function between the quadrature demodulated signals of sequentially received echoes, minute phase change of about 0.4 degrees caused by movement of the n-th point during the pulse transmission interval ΔT (=200 μs) can be accurately determined by introducing a *constraint*, namely, that their waveforms are identical but their phase values change. The lowest value of the change in thickness was validated as being about 0.5 μm by expanding a rubber plate in a water tank. Such a minute change in thickness cannot be measured by any other method. This method has already been applied to the *in vivo* detection of regional instantaneous displacement and change in thickness, with sufficient reproducibility, in the interventricular septum and in the CCA.