Detection of Atherosclerotic Lesions Based on Molecular Communication

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Abstract. Atherosclerotic plaques in the human circulatory system are a major cause of diseases in the blood vessels and the heart. These plaques can grow and block blood vessels, preventing blood from being supplied to the distal end. Mild to moderate stenosis does not cause a significant reduction in blood flow, and clinical signs do not appear unless the lesion has progressed to an advanced stage, and there is no reliable way to detect the lesion at early stages. Digital subtraction angiography is a commonly used method to detect atherosclerosis in medical clinics. DAS is considered to be "gold standard" for the diagnosis of vascular diseases. This article will analyze, model and evaluate the indicators of atherosclerosis development from the perspective of molecular communication and angiography. The main idea is to use the propagation of contrast agents as a function of the cross-sectional area of the blood vessel. Its specific implementation can be expressed by the propagation index of the contrast agent obtained after DAS processing. DAS processing is easily achieved in medicine. This article has practical significance for detecting similar vascular diseases.

Keywords: Molecular communication · Atherosclerosis · Das · Vascular occlusion
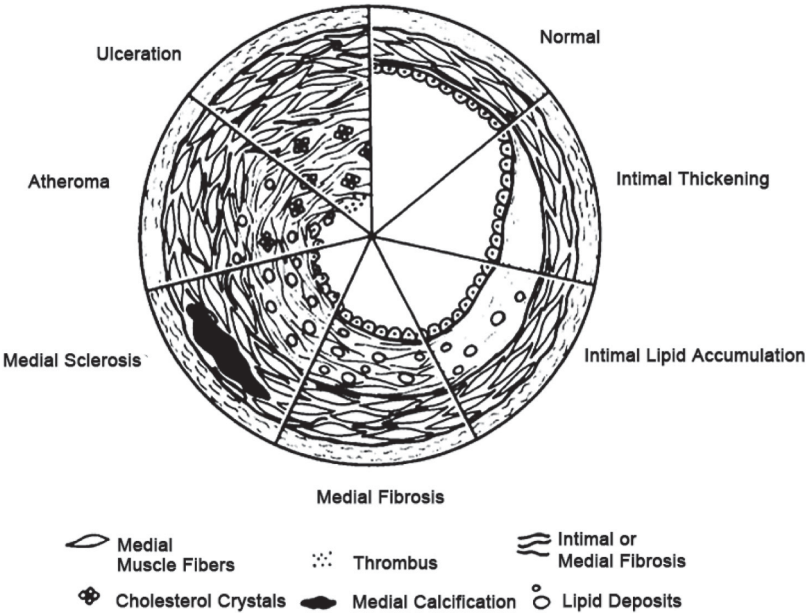
1 Molecular communication model

1.1 Atherosclerosis

The processes associated with atherosclerosis include lipid deposition under the endothelium, thickening of the intima, smooth muscle cell proliferation, and plaque formation. During the initial stages of atherosclerosis, LDL-cholesterol is excessively accumulated in the a cellular layer between endothelial cells and connective tissue. Here, LDL is oxidized and absorbed by macrophages through phagocytosis. When macrophages are filled with oxidized LDL-cholesterol, they release some paracrine substances, attracting smooth muscle cells to these areas, leading to the formation of lipid bands. Then, the newly formed cells in the

mesangium begin to migrate towards the intima and form some fibrous extra-cellular matrix. As cholesterol continues to accumulate, fibrous scar tissue forms around cholesterol. Migrating smooth muscle cells also divide and the intima begins to thicken. Intimal hyperplasia is a chronic response of vascular tissue to local blood flow and can lead to vascular occlusion. Intimal hyperplasia, abnormally accumulated lipids, calcium, macrophages from the blood, and necrotic tissue together form atherosclerotic plaques [1–3].

Atherosclerotic plaques grow and then protrude into the lumen, eventually blocking blood flow. As the initial lipid plaque develops into the calcified plaque in the intima of the blood vessel, the lumen cross-section for blood transport will gradually decrease [4] (Fig. 1).

Fig. 1. Representation of the cross-sectional area of blood vessels with the development of atherosclerosis

1.2   Vascular Modeling

The molecular communication model provides the possibility of modeling and detection, plus the angiography technology is easier to detect, that is, the concentration of the nano-robot reaching a certain position after being transmitted in the cardiovascular system is detected and displayed. The detection process is characterized by the probability of the nano-robot reaching the monitoring point after the contrast agent, that is, the fluorescent label $P_r(t)$.

Obviously, blood flow is significantly affected by the cross-sectional area of the blood vessel lumen. Using angiography to observe the difference in contrast agent concentration levels between diseased blood vessels and normal blood vessels at the same detection position at the same time. Nano-robots are contrast agents. Different vascular lumen cross-sectional areas during the development of atherosclerosis will cause different levels of nano-robot transmission.

Due to the beating of the heart, the blood flow velocity in the human blood vessel is a non-stationary flow that changes approximately periodically; and because of the mechanical characteristics of the blood flow, the blood flow velocity has a certain distribution in the radial direction of the blood vessel. The relationship between the detection probability of the nano robot and the cross-sectional area of the lumen is expressed as [5]:

$$P_r(t) = \pi r_0^2 m e^{-\frac{a\beta_\omega(t)F_S}{K_B r_0}}$$

where r_0 is the radius of the blood vessel; m is the initial concentration of the nanorobot; a is the size of the nanorobot (the radius of the nanorobot); Fs is the coefficient of vascular resistance; k_B is the Boltzmann constant: $k_B = 1.48066488 \times 10^{-23} \, \text{m}^2 \, \text{kgs}^{-2} \, \text{K}^{-1}$.

β is the coefficient of characterization of the shear stress of the blood vessel wall. Shear force refers to the friction between the blood flow and the endothelium of the blood vessel, which is closely related to blood characteristics, blood flow velocity and blood vessel shape. According to Womersley theory [6]:

$$\beta_\omega(t) = \frac{1}{2i\pi r_l} \int_{-\infty}^{+\infty} \frac{\alpha^2(\omega)W(\omega)}{1 - W(\omega)} U_l(\omega)e^{i\omega t} d\omega$$

Shear rate is time-varying and characterizes velocity gradients that are related to blood viscosity.

Where U is the Fourier transform of the average velocity of blood flow:

$$U_l(\omega) = \int_{-\infty}^{+\infty} u_l(t)e^{-j\omega t} dt$$

α is a dimensionless parameter called the instability parameter or the Wormsley number. Where the molecule represents inertial force, the molecule is viscous resistance, $W(\omega)$ is the Wormsley equation:

$$W(\omega) = \frac{2J_1(\alpha(\omega)i^{\frac{3}{2}})}{\alpha(\omega)i^{\frac{3}{2}} J_0(\alpha(\omega)i^{\frac{3}{2}})}$$

Where J_0 and J_1 are the zero-order and first-order solutions of the Bessel function of the first kind (Fig. 2).

Because the simulation experiment is carried out with the help of Labview tool, this conclusion is based on the laminar flow of the rigid channel. At the initial stage of the blockage of the blood vessel, the probability of the drug received at a fixed point is inversely proportional to the cross-sectional area of
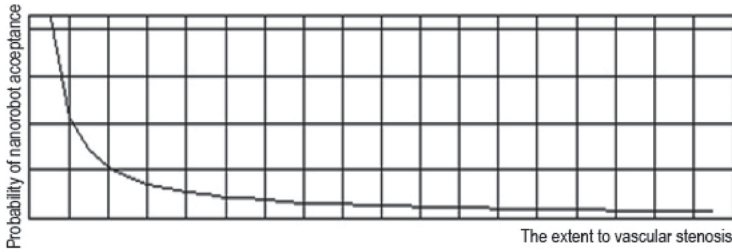
Fig. 2. Acceptance probability of drug receiving test site varies with blood vessel cross-sectional area

the blood vessel. When the blood vessel obstruction is more serious, as the cross-sectional area of the blood vessel decreases, and difficulty of blood flow passing further increases. Surely, for actual human blood vessels, the elasticity of the blood vessel wall must be considered. Generally, after the atherosclerotic plaque develops to a medium or higher level (50% to 99% of blood vessel obstruction), once the remaining part of the lumen encounters a blood clot, it will block blood flow. After a thrombus ruptures, as the blood flows to the distal branch arterioles, it can cause ischemia or necrosis of the tissue [7].

2   Conclusion

Atherosclerosis is a dangerous disease that not only blocks the arterial cavity, but also causes the plaque to rupture. If the fibrous cap that originally covered the area split, the highly thrombogenic surface will be directly exposed to the blood. With the development of the disease, the arterial vascular wall remodels. In order to adapt to the disease and the luminal cross-sectional area does not change, the vascular wall will become thinner. However, once the limit of vascular remodeling is reached, the diseased area begins to protrude into the tube area, the cross-sectional area of the blood vessel decreases, and blood flow is gradually blocked [8]. With the increase of occlusion, cross-sectional area of blood vessel circulation becomes smaller and smaller, and the hemodynamics of vascular stenosis become more complicated. This article uses the commonly used medical angiography technology to model the cross-sectional area of the blood vessel with the idea of molecular communication, and relates it to the more iconic nano-robot parameters, namely the contrast agent, to measure the development of atherosclerosis.

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