Modeling and flow simulation about coronary artery of infant

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Abstract

Kawasaki Disease is one of the diseases that children under four years old tend to contract. The definition of this disease are as follows

1. Lasting of high fever for more than 5 days.
2. Congestion of conjunctivas of both eyes
3. Strawberry tongue, red mouth and throat
4. Polymorphous rash in all body parts
5. [Acute stage] Swollen hands and feet
   [Convalescence stage] Desquamation from fingertips
6. Cervical lymphadenopathy in acute stage

In these major 6 symptoms, admission of Kawasaki Disease needs more than 5 symptoms. However, in some cases, it is admitted to be Kawasaki Disease in case of occurrence of just only 4 symptoms.

This disease was presented for the first time in the world by Tomisaku Kawasaki, Japanese doctor, in 1967. After that, other reports became to be made in all over the world. The number of patients is larger in Asia especially Japan than other region. After year of 1982 and 1986 that were epidemic period in which number of patients was about 15,000 a year, number of patients was about 6,000 a year for a while. However, recently, number of patients tends to increase gradually. Moreover, year of 2013 and 2014 had larger patients than year of epidemic, 1982 and 1986.

The cause of this disease has been known to be vasculitis which is damage of blood vessel by enzyme caused from white blood cell since the reaction to protect the self-body occurs too strong when invasion to the interior of the body is made by virus and so on. Nevertheless, the reason why this kind of reaction occurs has not been revealed and the trigger of this reaction has not been specialized.

Vasculitis sometimes makes aneurysms on coronary arteries of patients' heart. If there are aneurysms, thromboses are easy to be formed and that become the cause of heart attack. In other case, it is possible that the inner wall of coronary arteries that are damaged by vasculitis become atherosclerosis. Coronary arteries are important blood vessels that pomp blood to cardiac muscle making possible heart to beat. Thus, if these arteries has been injure, heart cannot maintain its function and that leads to the death in the worst case.

It is necessary to research the blood flow situation in the inner of coronary arteries to presume the damage of coronary arteries suffered from Kawasaki Disease. The first step for investigation of inner coronary arteries is visualization experiments or measurements of flow velocity or other flow index. However, it is difficult to implement those experiments with thinking about necessity of the expensive

apparatus or mature technique since the diameter of infant coronary arteries is very thin like as 1～2 mm. Moreover, inner flow of coronary arteries is very complicated since coronary arteries have viscoelastic characteristic on its wall and branching configuration. With thinking about uncertainty of measurement, it is almost impossible to grasp the inner situation experimentally.

Hence, simulation with numerical analysis is effectual method to reveal the flow situation of inner coronary arteries. Large-scale apparatus is unnecessary in numerical simulation and it is not limited physically despite the fact that it is necessary to confirm whether real phenomena is reproduced.

Complicated flow situation that was not able to be elucidated ever has been able to be analyzed in detail since the computational technique has been improved recently. There were some researches about flow in coronary arteries of Kawasaki Disease with numerical simulation. However, they treated vessel wall of coronary arteries as rigid body though these were viscoelastic intrinsically and they did not take into account that coronary arteries were forced to move periodically with synchronizing with heart beat since that blood vessel were on the outer wall of heart. Thus, inner flow of coronary arteries has not been elucidated so far.

In this research, to lay the foundation for estimation of the effect after recovery from Kawasaki Disease, vessel wall of coronary arteries is treated as viscoelastic body to investigate interaction between flow and vessel wall. Moreover, effect of displacement of coronary arteries was investigated.

Outline about these research are as follows.

Section 1 Background and purpose of this research were described.

Section 2 Numerical Simulation of the Flow in the Large Aspect Ratio Pipe with the Viscoelasticity Effect of Blood Vessel wall

As the first step to reveal the inner situation of coronary arteries, simple spring-dumper model was adopted as viscoelasticity of vessel wall. With that condition, it became capable to simulate with the effect of the force that wall receive from fluid flow. It was showed the necessity the analysis with viscoelasticity comparing with the case of rigid body.

Section 3 Numerical Analysis of Flow in a Hyperelastic Circular Tube Model of a Coronary Artery

Next, Mooney-Rivlin model was adopted as hyperelasticity that make possible to model more real vessel wall of coronary arteries. The situation of deformation of vessel wall was grasped.

Section 4 Numerical Analysis of Flow in the Branch Pipe with Hyperelasticity Modelling on a Coronary Artery

The method in Section 3 was applied to branching configuration that is characteristic to coronary arteries. The difference of flow situation between various branching angles was showed.

Section 5 Flow Simulation in the Pipe on the Sphere with Expand and Contract

To investigate extent that the flow was affected by heartbeat, pipe modeling coronary artery was set on the sphere which expands and contracts temporally. The characteristic flow situation was revealed.

Section 6 Conclusions and prospect were described.