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# The numerical simulation study of hemodynamics of the new dense-mesh stent

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**Abstract.** The treatment of aortic aneurysm in new dense mesh stent is based on the principle of hemodynamic changes. But the mechanism is not yet very clear. This paper analyzed and calculated the hemodynamic situation before and after the new dense mesh stent implanting by the method of numerical simulation. The results show the dense mesh stent changed and impacted the blood flow in the aortic aneurysm. The changes include significant decrement of blood velocity, pressure and shear forces, while ensuring blood can supply branches, which means the new dense mesh stent's hemodynamic mechanism in the treatment of aortic aneurysm is clearer. It has very important significance in developing new dense mesh stent in order to cure aortic aneurysm.

## 1. Introduction

With the improvement of the living standards of people, aortic disease, a great vessel dilated disease which has higher morbidity and mortality, increases rapidly <sup>[1]</sup>. Intracavitary minimally invasive interventional prosthesis has become a new clinical treatment method and is widely used in the treatment of all kinds of great vessels aneurysm disease based on the rapid development of interventional radiology and the research of intravascular stent <sup>[2]</sup>. The development and clinical application of the new type of stent which has greatly increased the success rate of surgery and simplify the clinical operation is a kind of mainstream treatment.

This research develops a new dense mesh stent mainly based on the current difficulties of the process of interventional therapy in which commonly the coated stent is used in the treatment of aortic aneurysm and the blood-supply of branch blood vessels is blocked at the same time. The new stent made of nickel titanium shape memory alloy mainly uses excellent phase change hyperelasticity, shape memory properties, good biocompatibility and corrosion resistance of the nickel titanium shape memory alloy and is a very excellent biomedical material. Based on the theory of reducing the mesh of stent making the hemodynamic change obviously <sup>[3]</sup>, multi-layer dense mesh stent will be produced and it will change the smooth of blood flow in aortic aneurysm, then it will allow blood to supply to the branch blood vessels and reduce the blood pressure and shear force of tumors so as to the goal of treatment will be achieved.

## 2. Materials and Methods

### 2.1 The Simulation of the Abdominal Aortic Aneurysm

For the convenience of the numerical simulation calculation and to ensure that the approximation of results of calculation and clinical actual state, the model size and the actual size is not completely



consistent, and the size is chosen to ensure that the Reynolds number approximation. Abdominal aortic aneurysm numerical model for geometric parameter is set as follows: abdominal aorta's diameter  $D = 12$  mm, aneurysm's diameter  $d_1 = 30$  mm, branch blood vessels' diameter  $d_2 = 6$  mm, artery' length  $L = 180$  mm, distance between the entrance and aneurysm  $L_1 = 60$  mm, the length of branch blood vessels  $L_2 = 40$  mm. Artery blood vessels and branch length are comparatively long to ensure the free flow of blood, which is closer to the clinical condition.

### 2.2 Physiological Condition Assumptions

Due to the special nature of the blood vessels and blood, some physical assumptions and reasonable simplification needed to be done before the simulation of stent implanting blood vessels and they can be as close to the ideal type of hemal wall and blood flow as possible 1) due to the numerical simulation results of the rigid hemal wall and flexible hemal wall are similar and the rigid hemal wall is easier to be handled, so the blood vessel and tumor walls are assumed rigid hemal wall; 2) the blood flow is named as Newtonian fluid<sup>[4]</sup>, which is incompressible. The blood flow form in the aneurysm<sup>[5]</sup> is set for laminar flow. Pulsed flow is used as blood flow. Heart rate is adopted as 72 times/min and the constant is adopted as the coefficient of blood viscosity; 3) the form of aortic blood flow is laminar flow generally.

The blood density:  $\rho = 1.05 \times 10^3$  kg/m<sup>3</sup>, the coefficient of kinematic viscosity = 0.0035 Pa/s,  $V = 0.3$  m/s,  $D = 0.12$  m,  $Re = 1080$ , which accords with the physiological condition of human body.

### 2.3 The Setting of Meshing and Boundary Conditions

Gambit software is used for meshing and the quadrilateral mesh grid is selected to divide and verify the model mesh of abdominal aortic aneurysm. In addition, the grid number is 11280, node number is 11789. Setting the inlet, outlet and boundary conditions: the inlet condition is set as speed inlet, the average speed  $v = 0.3$  m/s, the pressure of outlet including aortic outlet1 and branch vascular outlet2 takes the average pressure in artery blood vessel. In this paper, outlet pressure is set as  $P = 100$  mmHg (about 13.3 KPa) and abdominal aortic aneurysm boundary is set as solid wall boundary.

### 2.4 Calculation

With the fact of hemodynamics numerical simulation about abdominal aortic aneurysm in the condition of having and being without stents, the speed, shear force, pressure, streamline contours and the vector diagram are calculated under the above two cases by using Fluent, the commercial software of fluid mechanics. And through the map, the condition of different numerical changes and flow regime changes can be directly observed.

## 3. The Result Analysis

### 3.1 The Streamline Characteristics of Dense Mesh Stent Before and After Implanting

As the flow chart (Fig. 3.1) of dense mesh stent before and after implanting shows, a part of blood in the artery without implantation of stent flows into the tumor cavity and forms vortex, then a small amount of blood flows into the branch blood vessels after the vortex have twisted in tumor cavity, because most of blood flow in the tumor cavity don't be in the process of blood-supply for the branching vascular but twists in tumor cavity; When the dense mesh stent is implanted in the abdominal aortic aneurysm, a small amount of blood flow in arteries flows into the tumor cavity, and all flows into the branching vessels after slight twist. This suggests that when the stent is placed, it does not affect the blood supply of branching vessels but limits the small amount of blood flow that originally twists in the tumor cavity to flow into the tumor cavity at the same time, which radically reduced blood flow pressure and wall shear force in the tumor cavity.

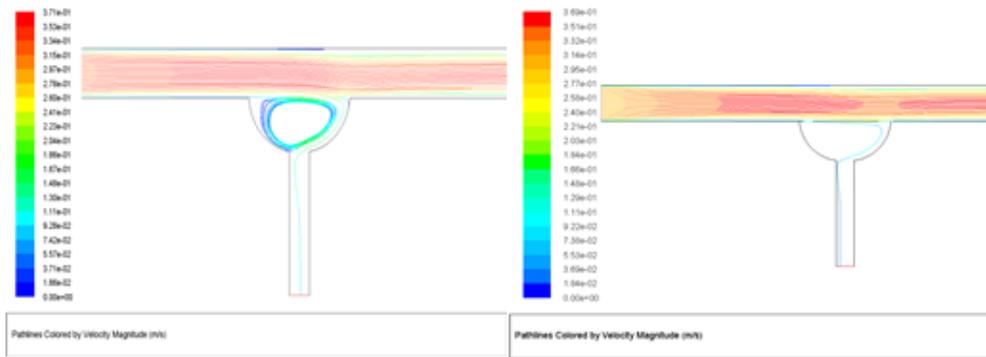


Figure 3.1 flow chart (a. no stent implanted b. with stent implanted )

### 3.2 The Velocity Field

The velocity distribution within the abdominal aortic aneurysm that having no stent implanted is listed as flows: Blood flow velocity in tumor cavity is lower than aortic's; Tumor cavity shows flow distribution in large eddy; Fringes of tumor cavity appear higher velocity.

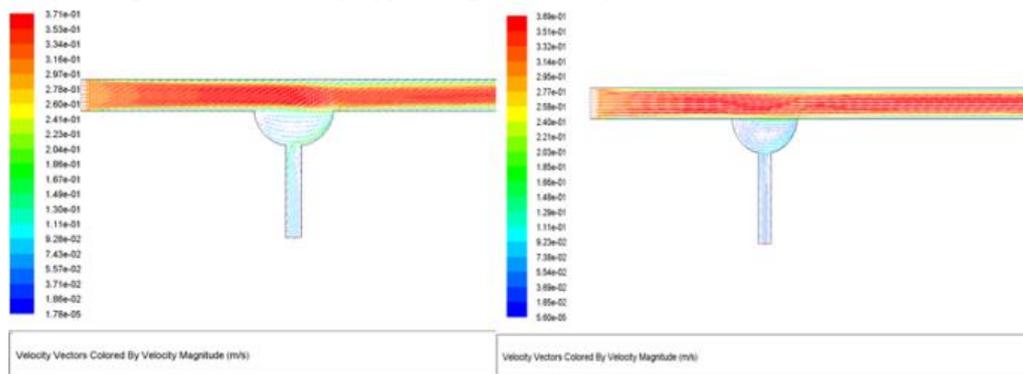


Figure 3.2 velocity chart (a. no stent implanted b. with stent implanted)

As the figure 3.2 shows: 1) The tumor cavity velocity with stent implanted was lower than that without stent implantation, and a large area of low speed flow area is showed as a whole; 2) The disturbance flow field in tumor cavity arises after the dense mesh implanted, and both the decline of velocity and flow distribution of disturbance flow can reduce the impact of the blood flow to tumors and reduce the risk of tumors' fracture. After calculating, it turns out that the flow rate in tumors with the dense mesh stent implanted is reduced by about 50.74%, and the flow rate in the neck of branch tumor is reduced by about 62.44%. This shows that the dense mesh stent implantation significantly reduces the blood flow velocity of the neck of tumors and tumors, and the risk of tumors' fracture is greatly reduced.

### 3.3 Pressure Field

From the figure 3.3, it can be directly observed that the color of tumor cavity with stent implanted is darker, and the disturbance state arises in the pressure chart. After numerical simulation calculating, it turns out that the pressure of tumors, tumor necks, branch vessels, and so on, with stent implanted is dropped respectively by 46.38%, 43.2% and 59.44%. This suggests that: 1) the blood pressure of tumor cavity, tumor cavity wall, tumor's neck and branch vessel is decreased, and the pressure distribution area is relatively scattered. So this can reduce the impact of the blood flow to tumors and the risk of tumors' fracture is also reduced; 2) the way of disturbance of flow state that in a model with stent implanted suggests that the decrease of the static pressure makes the flow state in the blood flow change, which will help for the thrombosis and create favorable conditions for the tumor wall reinforcement.

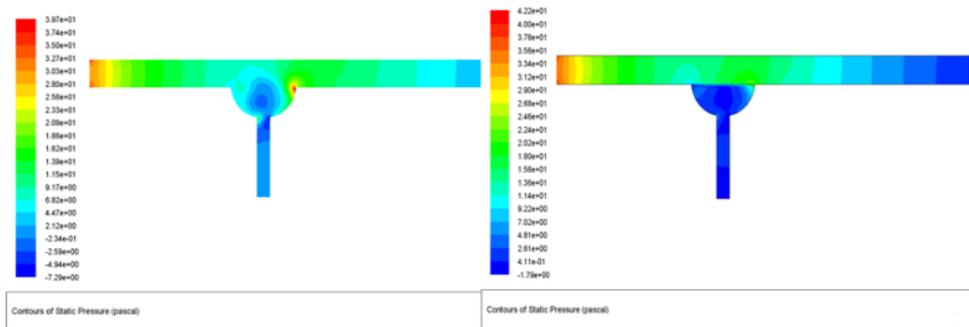


Figure 3.3 pressure field (a. no stent implanted b. with stent implanted)

### 3.4 The Wall Shear Force

As the figure 3.4 shows that the wall shear force in tumors with stent implanted is greatly reduced, especially in the place where tumors are the most easily broken<sup>[6]</sup>---- the wall shear force in the places where tumor necks of the connection between tumors and the arteries, and tumors and the branch vessel reduced a lot.

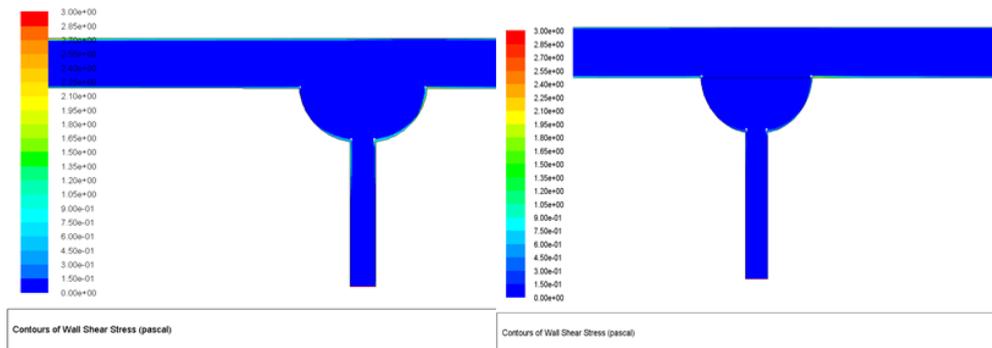


Figure 3.4 wall shear force (a. no stent implanted b. with stent implanted)

According to the Fluent software numerical simulation, it suggests that the wall shear force of aortic aneurysm neck, aneurysm neck of branch vessels, and tumors walls is dropped significantly, and the reduction rate is about 41.3% on average. This trend possesses extremely positive significance in the treatment of aortic aneurysm because the decrease of wall shear force in aortic aneurysm can directly reduce the possibility of tumors' fracture, and lipid deposition and the growth of the wall thickness also arise near the tumor wall, which will more directly play a role of thickening the wall and treating aortic aneurysm.

### 4. Conclusion

With the gradual understanding of etiology, treatment mechanism of aneurysm, hemodynamic factor is thought to have very important influence on the process of formation, development and rupture of aneurysm<sup>[7]</sup>. More and more domestic and foreign researchers have a study on hemodynamics of aneurysm<sup>[8]</sup>, and with the development of computer operation speed and software, the numerical simulation about hemodynamic factor in the aneurysm has become a very important technological research method<sup>[9,10]</sup>.

In this paper, the author aims to conduct hemodynamic numerical simulations of abdominal aortic aneurysm and abdominal aortic aneurysm with dense stent implanted. Under these two conditions, this paper respectively analyzes blood velocity contour, the blood flow velocity vector, pressure contour, wall shear force contour and streamline chart. The conclusions are listed as follows:

When the dense mesh stent is implanted in abdominal aortic aneurysm, it can reduce blood flow speed and pressure in the tumor cavity, and the wall shear force in aneurysm neck. In addition, it can form the spoiler to reduce the impact force of the fluid. Therefore, the implantation of a multi-layer dense mesh stent can reduce blood flow speed in tumor and the impact force, promote the lipids and cell

in blood to deposit, accelerate thrombosis, and strengthen aneurysm wall, so as to it can ensure the blood-supply of branch vessels, and promote thrombosis of that can lower risk of aneurysm rupture, and achieve the effect of the treatment of abdominal aortic aneurysm.

In this dissertation, the author has carried on the preliminary exploration of the hemodynamic mechanism of the dense mesh stent, but further simulation studies and the evaluation and analysis of vitro fluid test and animal test needed to be done if we want to thoroughly know the influence relationship between the structure of dense mesh stent and hemodynamic.

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