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Analysis of Endovascular Graft Features Affecting Endotension Following Endovascular Aneurysm Repair

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***Abstract*—**Endovascular aneurysm repair is a new and minimally invasive repair for patients with abdominal aortic aneurysm (AAA). This method has potential advantages that are incomparable with other repair methods. However, the enlargement of aneurysm in the absence of endoleak, which is known as endotension, may occur as one of post-operative compliances of this method. Typically, endotension is mainly as a result of pressure transmitted to aneurysm sac by endovascular installed graft. After installation of graft the aneurysm sac reduces significantly but remains non-zero. There are some factors which affect this pressure transmitted. In this study, the geometry features of installed vascular graft have been considered. It is inferred that graft neck angle and iliac bifurcation angle are two factors which can affect the drag force on graft and consequently the pressure transmitted to aneurysm.

***Keywords*—**Endovascular graft; transmitted pressure; Drag force; Finite Element Modeling, neck angle, iliac bifurcation angle.

I. Introduction

ABDOMINAL aortic aneurysm (AAA) is a localized dilatation of the abdominal aorta exceeding the normal diameter by more than 50 percent, and is the most common form of aortic aneurysm. Abdominal aortic aneurysms are found in up to 8% of men over the age of 65 years. Rupture of an AAA and its associated catastrophic physiological insult carries overall mortality in excess of 80%, and 2% of all deaths are AAA-related [1].

The most common treatment for a large (>5 centimeters), unruptured aneurysm is open surgical repair by a vascular surgeon. The aneurysm is cut and sewn in a graft to act as a bridge for the blood flow. The blood flow then goes through the plastic graft and no longer allows the direct pulsation pressure of the blood to further expand the weak aorta wall [2].

Interventional Repair is a less invasive method of placing a graft within the aneurysm to redirect blood flow and stop direct pressure from being exerted on the weak aortic wall. This relatively new method eliminates the need for a large abdominal incision. It also eliminates the need to clamp the aorta during the procedure. Clamping the aorta creates significant stress on the heart, and people with severe heart disease may not be able to tolerate this major surgery [3~6].

The most complicated EVAR post operation compliance is aneurysm growing even in the absence of endoleak and this is considered to be a treatment failure with risk of rupture. This condition described as ‘‘endotension’’ [4]. While the pathophysiology of other EVAR post operation compliance is beginning to be elucidated, controversy still exists about the etiology and clinical consequences of endotension.

White et al [7] defined endotension as a phenomenon in which postoperative high intrasac pressure occurs in the absence of continuous perfusion of the aneurysm sac. This persistent pressure may lead to enlargement of the sac, and was termed endotension or endoleak. There are several mechanisms by which pressure can be transmitted to the aneurysm sac and cause endotension [8~19], [25].

The transmission of pressure from endovascular graft to the aneurysm sac can occur via thrombus layers between the aortic wall and the graft. The aneurysm wall has lost its elastic properties due to abdominal aortic aneurysm. Therefore even a small transmitted pressure can cause huge enlargement in aneurysm sac. The blood flow stream causes drag force on graft wall. This drag force can lead to deformation or even migration of graft. The magnitude of this drag force depends on multi-factors. The graft neck angle and iliac bifurcation angle are two factors that play more important role in affecting drag force on graft. Hence, in this study, in order to review the effect of neck and iliac bifurcation angle, Finite Element Modeling of aneurysm sac and installed graft is employed.

II. Materials and Methods

Computational Finite Element models of AAA have been constructed using CT-Scan images data of the experimental AAA models. The CT-Scan images have been converted to 3-D CAD model by Mimics 10.01 software. Following the CAD profiles, we used GAMBIT 2.3.16 software to build the graft, aneurysm sac and wall. These models then have been imported to ANSYS FLUID FLOW (CFX) version 12 for linear and nonlinear analyses and solve this fluid structure (FSI) problem. Fig.1 depicts one sample of these Finite Element models.

The interacting materials include the blood, graft wall, stagnant blood in the aneurysm cavity, and its wall. The cavity has been assumed to be filled with thrombus blood, i.e., no endoleak in the aneurysm models. Also, to simplify the simulations, the blood flow has been considered to be

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incompressible and laminar. The material properties in the Finite Element Modeling have been assumed to be isotropic and linear. No residual stresses and tissue growth on the walls have been considered. The structural parameter values which have been used in this paper are listed in Table I.

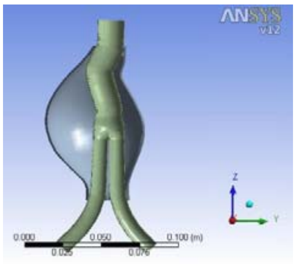

Fig. 1 Graft, Aneurysm sac and wall

TABLE I
PARAMETERS REQUIRED IN THE SIMULATION

Parameters	Aneurysm	graft
Wall thickness	1.3mm	Equivalent: 0.3mm
Diameter	55mm	Main body diameter: 15mm Iliac leg: 11mm
Length	80mm	Main body: 55mm Iliac leg: 60mm
Young's modulus	4.66MPa	Equivalent: 10MPa
Poisson ratio	0.45	Equivalent: 0.27
Density	1.12 g/cm3	Equivalent: 6.0 g/cm3

In this paper, several graft geometries have been considered. The variable parameters are graft neck angle and iliac bifurcation angle. For a bifurcated NiTi stent interwoven with graft material, an equivalent Young's modulus for the uniform graft configuration was assumed to be 10MPa [26], because no direct experimental data was available.

The average Reynolds number of 330 has been considered in the inlet of graft with uniform and fully developing fluid. For the outlet pressure, the peak and average pressures are assumed to be 125 and 98.7mmHg, respectively [27]. The boundary conditions have been considered as fixed DOF condition (with no movement and rotation) at the inlet and outlet, and free DOF on walls. The "CFX tetrahedrons" and "Brick 20 Node" mesh elements are applied for fluid and solid meshing, respectively. In addition, meshes were refined to satisfy the criteria for mesh convergence. In addition, these meshes are compatible with fluid structure interaction (FSI) modeling. The Figs. 2~4 show the procedures considered for these Finite Element models.

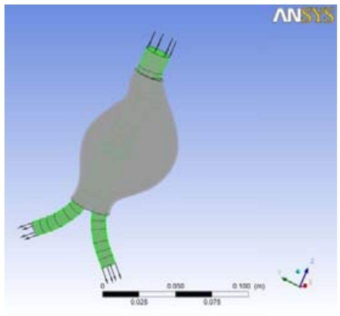

Fig. 2 Inlet and outlet fluid direction in graft

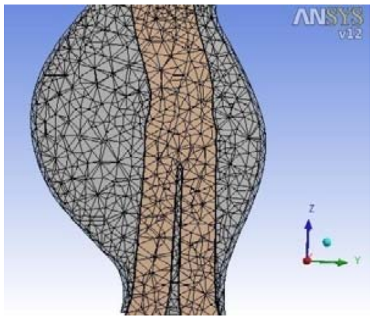

Fig. 3 Generated mesh on ANSYS CFX model

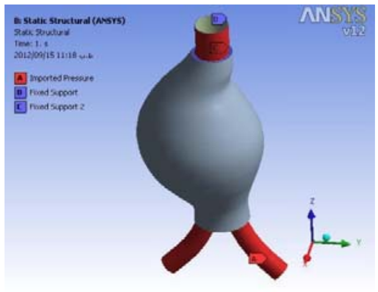

Fig. 4 Applied boundary condition on model

The drag force exerted on the graft, due to fluid friction and net momentum change, has been computed from surface integration of pressure and wall shear stress under the condition of each modeling. Solving this Finite Element model, resulting Von-Mises, shear mechanical stress and deformation which are generated on aneurysm sac wall as consequence of blood flow on graft is calculated

III. RESULTS

It is obvious that, the inlet aneurysm neck angle is one of the effective factors which influences the pressure transmitted to aneurysm sac wall. The blood flow direction is changed by passing through this neck angle. As a result, the magnitude of transverse load on graft wall will increase greatly. Additionally, in some specific neck angles, the changing in blood pressure stream would be to some extent that blood vortexes appear in this area. Therefore, the blood vortexes loads would be added to other kind of load in this part [20~25]. Obviously, increasing loads on graft wall leads to growing graft wall deformation which can transmit pressure to aneurysm wall that may contribute to endotension. To review effect of graft neck angle on graft drag force, in Finite Element Model, Fig.1, by changing the neck angle the magnitude of drag force on graft obtained. The blood flow stream on graft has been illustrated in Fig. 5. This depicts the changes in blood velocity as it flow in graft.

As a result of pressure transmitted to aneurysm sac, the von-Mises, shear stress and deformation of aneurysm sac wall are changed. These have been shown in Figs. 6~8.

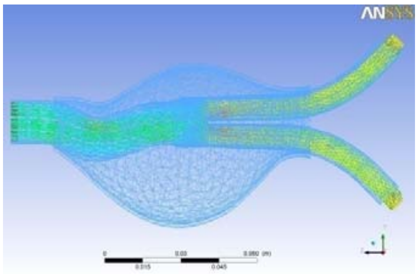

Fig. 5 Blood flow stream in graft

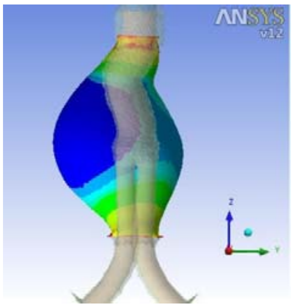

Fig. 6 Von-Mises stress on aneurysm sac wall

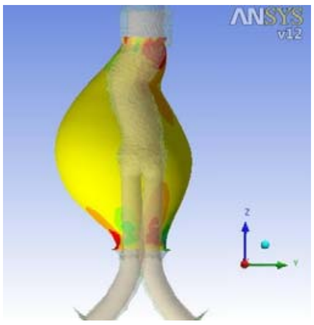

Fig. 7 Shear stress on aneurysm sac wall

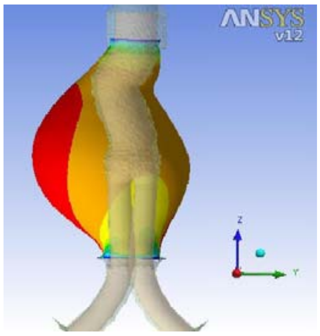

Fig. 8 Deformation on aneurysm sac wall

It can be inferred that after implanting the graft the stress on aneurysm sac wall is still non zero and it can contribute to deformation on wall and result to endotension. Fig.9 depicts the relation between magnitude of graft drag force and graft neck angle. It can be inferred from Fig.9 that increasing the neck angle contributes to increasing graft drag force.

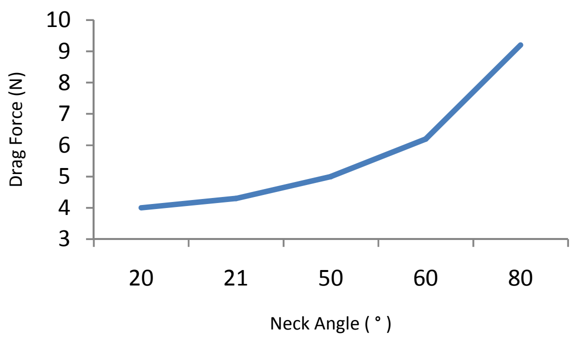

Fig. 9 Relationship between graft drag force and neck angle

Stress concentration can also be an effective factor which intensifies the magnitude of loads on graft wall measurably. Stress concentration mainly caused by changing in blood flow momentum. The geometrical features of graft such as iliac bifurcation angle, Fig. 1, graft size and aorta-to-iliac diameter ratio have significant effects on changing blood flow net momentum. The mail area of stress concentration is in the junction of bifurcation iliac, which blood flow should divide into two bifurcations iliac. The drag force in this junction part is critical also, that makes this part so important to consider as a main part for graft large deformation or even migration. By changing the iliac bifurcation angle in Finite Element Model the different magnitude of drag forces are obtained and shown in Fig. 10. It can be concluded that increasing iliac bifurcation angle results in increasing graft drag force.

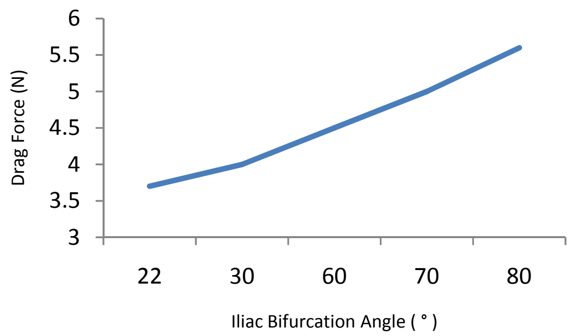

Fig. 10: Relationship between graft drag force and iliac bifurcation angle

IV. Discussions

As it mentioned, endovascular graft plays a key role in pressure transmission to aneurysm sac and consequently endotension. The geometrical features of graft such as neck angle and iliac bifurcation angle are the factors which can affect the magnitude of drag force which transmitted from blood flow stream to graft. This force can transmitted to aneurysm sac which may followed by endotension. Furthermore, graft migration may be followed by this drag force.

As a result, for choosing a proper endovascular graft, that it is so essential that the graft tolerates the blood pressure loads, such as drag or migration loads. Also, it should be considered that in addition to graft material, graft geometrical properties can influence the transmitted pressure to aneurysm sac. Specifically, graft size, AAA neck angle, iliac bifurcation angle have significant effect on fluid flow forces which potentially lead to graft migration or endotension.

It should be noted that there are some other factors which can influence the magnitude of graft drag forces and consequently pressure transmitted to aneurysm sac, which is known as one of significant reasons of endotension. Graft material, high ductility property of graft, graft size, aorta-to-iliac diameter ratio and pulsatile nature of blood pressure are some kinds of these factors.

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