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Temporal analysis of the fistula at three anastomosis angles of 45, 90, and 135 degrees

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ABSTRACT: Selection of the appropriate anastomosis angle for the creation of a fistula for surgery is very important. Therefore, in this study, three anastomosis angles of 45, 90, and 135 degrees, representing acute and obtuse angles, are designed and simulated in a complete pulsation cycle. Carreau non-Newtonian blood model is used and the flow is considered as incompressible flow. Finally, after modeling, important parameters such as mean shear stress on the fistula wall, oscillatory shear index, relative residence time, and maximum pressure drop are extracted and compared at different angles. After comparing the results, it is observed that the time average wall shear stress and the range of the high shear stress at anastomosis angle of 135 degree is lower than the two other angles and the probability of thrombosis disease in this angle is reduced. 80% of fistula failure is caused by thrombosis disease, therefore this angle is chosen as the most appropriate angle for fistula creation. Based on the results of the relative residence time, it is found that at all three angles of anastomosis, the right branch of the fistula and flow separation sites have a probability of sedimentation and it decreases at an angle of 135 degree. This angle also has the lowest pressure drop between the main inlet and the fistula outlet.

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1- Introduction

Arteriovenous fistula is the most common method of treatment in patients with Kidney failure [1] and it was first suggested in 1973 by Karmody and Lempert [2] and has been used from the radial artery and the cephalic vein located on the wrist to create it [3]. Fistula failure is the main problem of using a fistula after its creation. Previous studies have shown that high and low shear stress causes thrombosis and oscillating WSS gradually causes sedimentation in the fistula [4]. Eventually, these two factors reduce the fistula's blood current and make it ineffective [5]. Sedimentation and thrombosis completely depend on the angle of anastomosis between the artery and the vein to create the fistula.

In this paper, in order to determine prone areas of thrombosis, areas with the probability of sedimentation as well as pressure drop created between inlet and outlet of fistula, anastomosis with 45, 90, and 135 degrees angles are simulated in 3D. Then, using the heart pulsation cycle, the geometries are simulated in the OpenFOAM software and the performance of these anastomosis is analyzed.

2- Equations

In this study, the averaged continuity and momentum equations and the $SST-k\omega$ turbulence model [6] are used. Flow is incompressible and the blood is considered non-Newtonian with Carreau model [7]. Three important parameters including $TAWSS$ which represents the mean shear stress on the fistula wall, OSI, or oscillatory shear index in which represents the flow oscillatory behavior [8], and RRT is the relative residence time, are considered in modeling of pulsatile mode [9]. This parameters are expressed as follows:

$$TAWSS=\frac{1}{T}\times\int_{\alpha}^{T}\left|\overrightarrow{WSS}\right|dt \qquad (1)$$

$$OSI=\frac{1}{2}\left[1-\frac{\left|\int_{0}^{T}\overrightarrow{WSS}dt\right|}{\int_{0}^{T}\left|\overrightarrow{WSS}\right|dt}\right] \qquad (2)$$

$$RRT=\left[(1-2\times OSI)\times TAWSS\right]^{-1} \qquad (3)$$

3- Numerical Method

In the present simulation, the first-order Euler's method for time termes and the limited linear combination method [10], for convection terms of momentum transfer equations, k and ω, and the second-order central method for diffusion terms are used. Designed geometries were simulated using a pimpleFoam solver, which is a transient solver for an incompressible flow [11]. The blood pulsation curves were used in two fistula inlets for boundary conditions [12].

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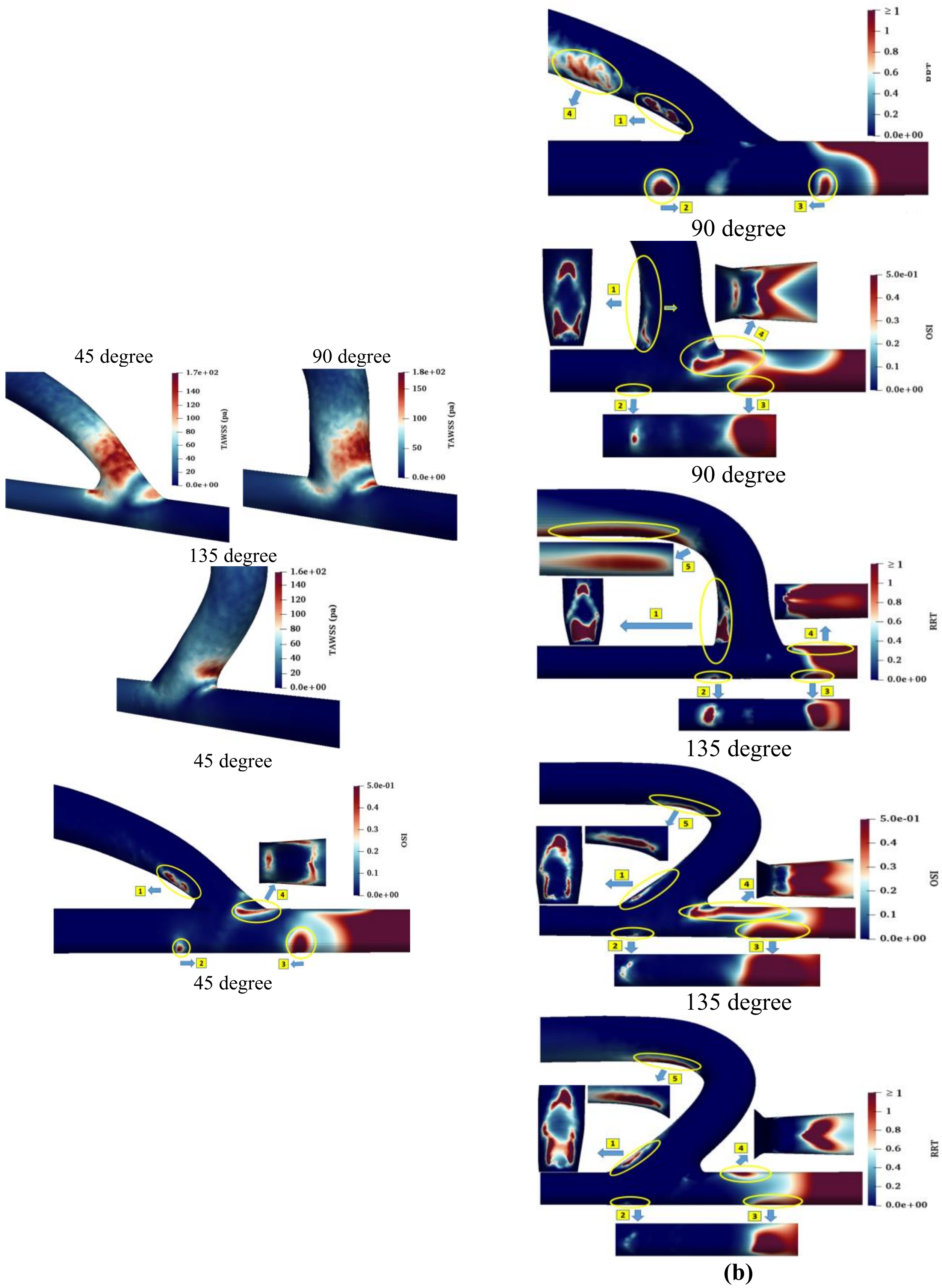

Fig. 1. Contours of susceptible areas at different anastomosis angles

4- Results and Discussion

The results of the simulation show that the 135 degree angle has the lowest average shear stress (157 Pa) and at this angle, the areas involved in high shear stress at the anastomosis are lower than other angles. Based on the results of the *RRT*, it is observed that the regions at the site of distal artery due to redirection of blood flow, the oscillation of the flow, and low shear stress (approximately zero), are at risk of sedimentation and blocking the flow of blood. This risk at 135 degree angle is less than two other angles. A comparison between the pressure drop curves shows that the pressure drop at the 135 degree anastomosis decreased by approximately 34% relative to the 45 degree anastomosis.

5- Conclusions

For all three angles, maximum *TAWSS* occurs on the right wall at the site of anastomosis, and in this area thrombosis is likely to happen. This risk is reduced at an anastomosis angle of 135 degrees. A comparison between the contours of *OSI* and *RRT* indicates that the oscillatory zones do not necessarily show the areas at risk of sedimentation, and a parameter called low shear stress is also involved in determining the areas at risk of sedimentation. Hence the simultaneous effect of these two parameters should be considered. Areas at risk of sedimentation are reduced at 135 degree anastomosis. The results of the pressure drop also show that a 135 degree anastomosis creates the lowest pressure drop. Eventually, it can be concluded that a 135 degree angle is the best choice for surgeons to create a fistula.

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