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

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ABSTRACT

Selection 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 TAWSS, OSI, RRT 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, therefor this angle is chosen as the most appropriate angle for fistula creation. Based on the results of the RRT in which are shows areas of sediment, it is found that at all three angles of anastomosis, the right branch of the fistula and flow separation sites have probability of sedimentation and it decreases at angle of 135 degree. This angle also has the lowest pressure drop between the main inlet and the fistula outlet.

KEYWORDS

Hemodialysis, fistula anastomosis angle, thrombosis, heart pulsation cycle, atherosclerosis

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1. Introduction

Arteriovenous fistula is the most common method of treatment in patients with Kidney failure [1] and it was firstly suggested in 1973 by Karmody and Lempert [2] and have 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 creation of it. 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 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 a non-Newtonian blood 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 parameter are expressed as follows:

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

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

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

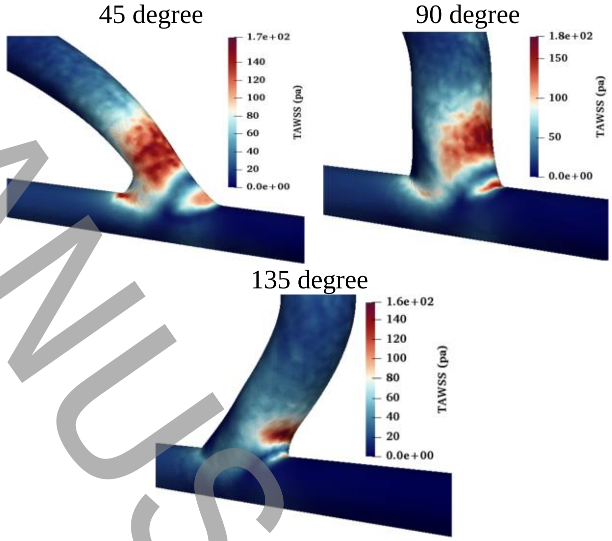
3. Numerical method

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 w, and the second-order central method for diffusion termes are used. Designed geometries were simulated using a pimplefoam solver, which is a transient solver for an incompressible flow [11]. The blood pulsation curve were used in two fistula inlets for boundary conditions [12].

4. Results and Discussion

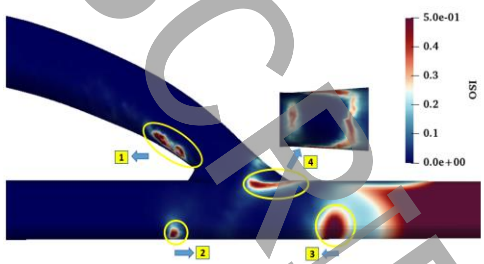
The results of simulation show that the 135 degree angle has the lowest average shear stress (157 Pa) and at this angle the areas involved in high shear stress at the anastomosis is lower than other angles. Based on the results of the RRT, it is observed that the regions at the site of distal artery 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.

45 degree 90 degree

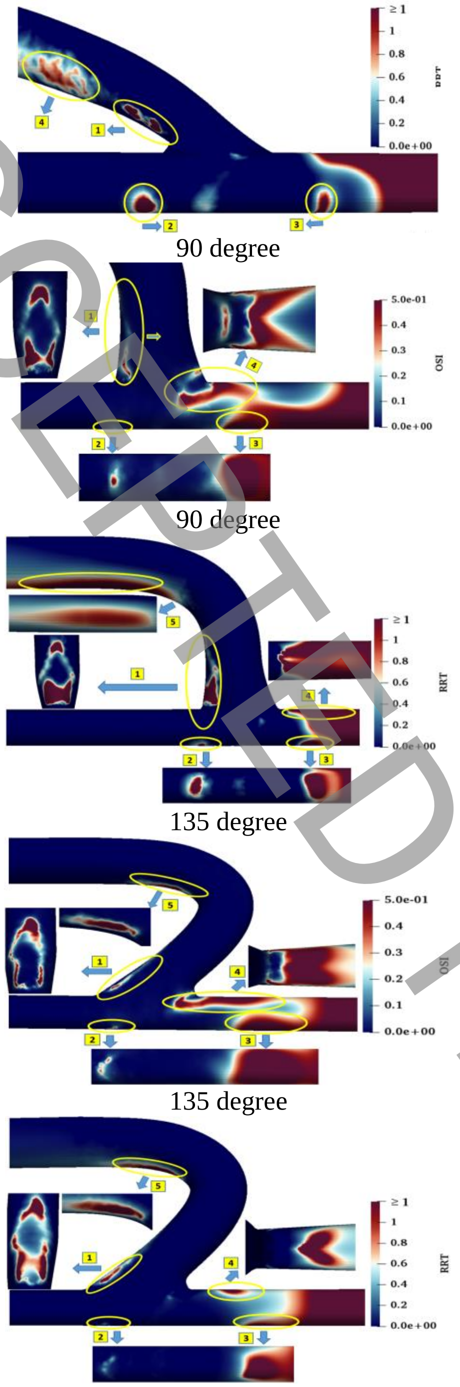


135 degree

45 degree



45 degree



(b)

Figure ١: Contours of susceptible areas at different anastomosis angles

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 parameter should be considered. Areas at risk of sedimentation are reduced at the 135 degree anastomosis. The results of the pressure drop also show that the 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.

6. References

[1] B. Ene-Iordache, C. Semperboni, G. Dubini, A. Remuzzi, Disturbed flow in a patient-specific arteriovenous fistula for hemodialysis: multidirectional and reciprocating near-wall flow patterns, Journal of biomechanics, 48(10) (2015) 2195-2200.
[2] A.M. Karmody, N. Lempert, “Smooth loop” arteriovenous fistulas for hemodialysis, Surgery, 75(2) (1974) 238-242.
[3] A. Bode, J. Tordoir, Vascular access for hemodialysis therapy, in: Modelling and Control of Dialysis Systems, Springer, 2013, pp. 235-303.
[4] F. Curtolo, Nuova metodologia basata sull'elaborazione di immagini da UltrasoundÂ® per la modellazione e la simulazione numerica della fistola artero-venosa. A novel protocol based on UltrasoundÂ® imaging for patient specific AVF modelling and numerical simulation, (2017).
[5] A.M. Malek, S.L. Alper, S. Izumo, Hemodynamic shear stress and its role in atherosclerosis, Jama, 282(21) (1999) 2035-2042.
[6] D.C. Wilcox, Turbulence modeling for CFD, DCW industries La Canada, CA, 1998.
[7] A. Razavi, E. Shirani, M. Sadeghi, Numerical simulation of blood pulsatile flow in a stenosed carotid artery using different rheological models, Journal of biomechanics, 44(11) (2011) 2021-2030.
[8] A. Caballero, S. Laín, A review on computational fluid dynamics modelling in human thoracic aorta, Cardiovascular Engineering and Technology, 4(2) (2013) 103-130.
[9] J.V. Soulis, O.P. Lampri, D.K. Fytanidis, G.D. Giannoglou, Relative residence time and oscillatory shear index of non-Newtonian flow models in aorta, in: 2011 10th international workshop on biomedical engineering, IEEE, 2011, pp. 1-4.
[10] H.K. Versteeg, W. Malalasekera, An introduction to computational fluid dynamics: the finite volume method, Pearson education, 2007.
[11] G. Holzinger, OpenFOAM: A little User-Manual, CD-Laboratory-Particulate Flow Modelling, Johannes Keplper University: Linz, Austria, (2015).
[12] S.C. Park, R. Song, S. Kim, H.K. Kim, S.-H. Kim, J. Lee, Fabrication of artificial arteriovenous fistula and analysis of flow field and shear stress by using μ-PIV technology, Journal of Mechanical Science and Technology, 30(12) (2016) 5503-5511.