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Study of constricted blood vessels through ANSYS fluent

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ABSTRACT

Blood vessels of humans may constrict due to different reasons reducing the internal diameter available for blood flow. In broader spectrum this phenomena is known as vasoconstriction. The constricted blood vessels offer greater resistance to the normal blood flow which may severely affect the connected human organs. Circumstances at point of constricting may worsen hemodynamically. One of most commonly occurring disease is Raynaud's syndrome, where the blood vessels in hands constrict either reducing or completely blocking normal blood flow. In the current study, ANSYS simulation are used to estimate the pressure and velocity variations in constricted vessels. The results showed that velocity and pressure of blood may reduce up to 50% and 40%, respectively after passing through the constricted area. The results of this study will be helpful for the comprehension of sophisticated hemodynamics at constricted vessel portion and hence better remedial measures may be adopted.

Keywords: ANSYS, Constricted blood vessels, Raynaud's syndrome, Hemodynamics

INTRODUCTION

Blood vessels may constrict in internal diameter due to multiple reasons. Their constriction offer new challenges to the dynamics of blood flow. In constrictions vessels contract from the center reducing the diameter they offer for blood passage (Sharma and Yadav 2017). This may be caused by the swelling of muscles supporting the body organs resulting in the occupation of more space and hence reducing the available volume for blood flow. Secondly, this may be caused by the deposition of internal materials (fats etc.) reducing the cross sectional area available for normal blood flow (Bächer, Schrack et al. 2017). It means that the blood flow must be affected with these reasons.

Blood flow when reach to point of constriction will behave like the Bernoulli's theory; if veins are horizontally structured. It is well known fact that all veins in human body are not placed horizontally and moreover the flexibility of human torso affect the positioning of veins. Therefore, gravity always comes to affect the blood flow dynamics (Sirohey, Licato et al. 2016). Volume of blood quantity flowing per unit time from any cross section is called blood flow. Normally flow of blood is referred to its movement in vessels, organs and tissues. Blood flow is initiated from hear when its ventricles contract causing ejection of blood in the body system and faces resistance at constriction point. The resistance at constriction point may cause inflammation depending upon the severity of constriction (Chang, Zeng et al. 2016).

In most of cases the blood pressure before the constricted area will cause dilation of vessel prior to constriction area. In case of upper skin layers, the veins often become visible because of increased cross section. Reduced blood supply because of constriction may affect the organs getting supply form vessels (Chang and Zhang 2018). The central constriction of veins is more commonly seen in the veins of hands and this phenomenon is more commonly known as Raynaud's syndrome. The hands or feet affected by Raynaud's syndrome often are cut short of blood supply turning them pale or blue. In more acute

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cases the blood supply is completely blocked because of constriction of blood vessels which exist in fingers. This syndrome may leave the fingers unable to perform normal functions (Landry 2017, Brown and Kimbel 2019).

Hemodynamics at constriction has been in lime light for many years as it may have negative impacts on connecting organs (Westerhof, Stergiopulos et al. 2019). Researchers are trying to throw more light on veins affected form constriction in order to device better counter strategies to deal with associated negative effects. Immediate diagnosis is another key interest of researchers.

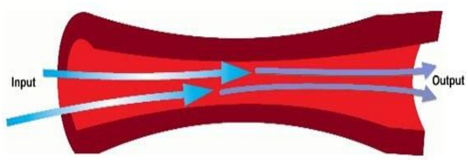

Fig. 1: Constricted blood vessels

Vasoconstriction is when muscles of blood vessels contract reducing the available volume for blood flow (Chen, Xu et al. 2019). On contrary side in vasodilation the muscles of blood vessels expand to make more space available for blood to flow.

In hemorrhage and intense blood loss, the process of vasoconstriction is of vital importance (Schiller, Howard et al. 2017). Constriction of blood vessels cause reduced or decreased blood flow which result in maintaining body heat or augmenting vascular resistance. In this situation, the skin of affected individual turn paler because of least blood availability and this condition decreases the radiation of heat. In broader spectrum, body regulates and maintains mean arterial pressure in vasoconstriction (Moral-Sanz, Lewis et al. 2018). Usually systematic blood pressure increases in vasoconstriction, but it may cause some localized blood flow reduction if happened in any specific tissue. The severities of vasoconstriction always depend upon the circumstances. In case of intermittent claudication the extent of vasoconstriction may get severe. Some of drugs are considered as cause of vasoconstriction. Normally antihistamines, decongestants, amphetamines, stimulants and cocaine cause vasoconstriction. Long time exposure of body to cold may end up in concomitant vasoconstriction (Ducros and Wolff 2016).

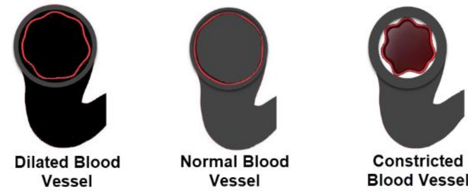

Fig. 2: Constricted blood vessel in comparison with dilated and normal blood vessels

A clear constricted difference has been shown in this Fig 2. When the blood vessels squeezed by applying some pressure then its shape has been modified. This shows vasoconstriction. High concentration of calcium (Ca^{+2} ions) within vascular smooth muscle cells may end up in vasoconstriction. However, the specific mechanisms for generating an increased intracellular concentration of calcium depend on the vasoconstrictor. In normal healthy body the process of vasoconstriction may occur to control blood pressure, to control body heat loos in cold environment, blood distribution management, supply excessive nutrients and oxygen delivery of need basis or to save book and fluid in body. In this study, only the central constriction of blood vessels is considered (Cseplo, Vamos et al. 2017).

The blood flow rate and blood velocity have been examined and matched with constant and variable blood viscosity for constricted blood vessels (Tiwari and Chauhan 2019). The results presented for constricted blood vessels by numerical modeling and geometric characterization of the constricted areas for complete understanding of the underlying Physics (Carboni, Bognet et al. 2018).The investigation of constricted blood vessels has also been carried out for the constriction with suitable modelling of blood flow such that the findings of velocity of blood for induction of decreased wall stress (Shahid 2019). Many researchers has investigated blood flow with the help of ANSYS (Afzal , Afzal, Tayyaba et al. 2017, Afzal, Tayyaba et al. 2017, Afzal, Ashraf et al. 2018). In this study, the authors have been investigated the variation of blood velocity with the increase in pressure through constricted portion of the blood vessels by using ANSYS Fluent. ANSYS is a useful tool for the simulation of blood flow parametric estimation.

ANSYS simulation for constricted blood vessel

A constricted blood vessel is designed in design modeler of ANSYS 18.2. The length of the vessel was taken 10 mm. The constricted portion of the vessel was taken as 6 mm. The diameter was kept 1 mm, and 0.5 mm was taken for the constricted portion. The complete design of the vessel is given in design Modeler (Fig. 3).

After designing, mesh analysis was done by creating 15850 nodes and 78092 elements in the vessel. It is shown in mesh Analysis (Fig. 4).

The pressure contour has been presented in Fig. 5. This contour shows that how pressure has changed along the length of the pipe. The maximum pressure at the red color was taken 1.008 K Pa. This pressure is reduced up to 62.97 Pa along with the vessel length.

The velocity contour has been presented in Fig. 6 below. The maximum velocity was measured 1.851 cm/sec. It is due to the 50 % constriction in the blood vessel. This contour presented the reduction in the velocity from middle to the periphery of the vessel. The minimum velocity was measured up to 0.1157 cm/sec.

The velocity streamline contour is presented in Fig. 7 below. This contour presented the blood flow pattern without the blood vessel. Only the streamline flow has shown in this contour diagram with the average speed of the blood.

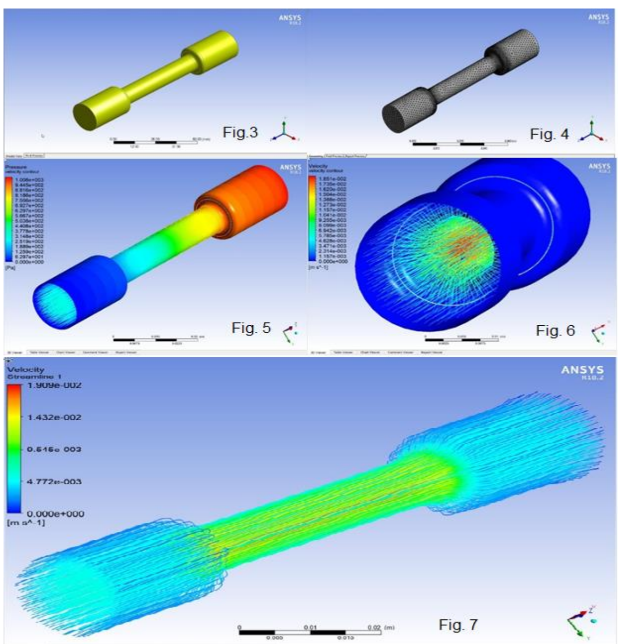

Fig.3 to 7 (3 design modeler, 4 mesh analysis, 5 pressure contour, 6 velocity contour and 7 Velocity Streamline Contour)

The velocity obtained in ANSYS Fluent simulation is 1.851 cm/sec. Actual flow velocity is up to 4 cm/sec without constriction (Lee and Fung 1970).

Table I: Results of pressure and velocity variation

Velocity (m/s)	Pressure (Pa)
0.01851	62.97
0.01735	125.9
0.0162	188.9
0.01504	251.9
0.01388	314.8
0.01273	377.8
0.01157	440.8
0.01041	503.8
0.009255	566.7
0.008099	629.7
0.006942	692.7
0.005785	755.6
0.004628	818.6
0.003471	881.6
0.002314	955.5
0.001157	1008
0.01851	62.97
0.01735	125.9

This table shows that pressure is increasing step by step and velocity is decreasing gradually. Initially, when pressure is 62.97 Pa then velocity is 0.01851 m/s. Finally, the pressure becomes 125.9 Pa and velocity is just 0.01735 m/s.

The final results presented by the reduction in external and internal diameter. The external diameter is 1 mm of this blood vessel and flow velocity has been reduced by almost 50 % with insignificant reduction in rate of blood flow. Similarly, internal diameter can further be reduced up to 70 % and then blood flow rate will be affected significantly (Mann, Herrick et al. 1938). From the results of ANSYS Fluent 18.2 simulation, graph between pressure and velocity with error bars of standard deviation has been shown below in Fig. 8.

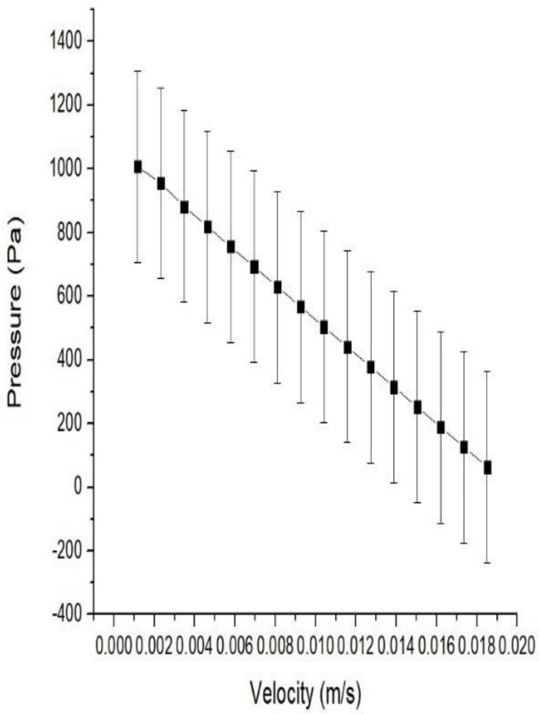

Fig.8. Graph between Pressure and Velocity

This graph presents an inverse relation between pressure and velocity inside the constricted blood vessel. When pressure is exerted more and more the velocity of blood decreased less and less. The graph shows statistical results with standard deviation (1sd of 300.864) in each result. There is no drastic deviation between all results of velocities and pressure.

This graphical explanation in Fig.9. has shown that how blood velocity has decreased percentage wise at every point with pressure upsurge. The minimum decrease is 0.73% at initial stage and 11.75% at final stage.

CONCLUSION

In Raynaud's syndrome, the central constriction of blood vessels is more commonly seen in hands, feet and other parts of the body. The blood supply can be completely blocked because of constriction. It may leave affected organs unable to perform regular functions. This research got its importance in studying the blood velocity in the constricted portions with the help of ANSYS. ANSYS Fluent is very helpful to understand the behavior, blood flow pattern, blood velocity (1.851 cm/sec) and the blood pressure (1.008 K Pa) inside the blood vessels. Moreover, it can be helpful for the diagnosis of certain diseases. In case of permanent constriction, better Hemodynamics understanding at constriction point will provide good basis for future course of action. Hence, this study is necessary before the fabrication of bio-engineered blood vessel.

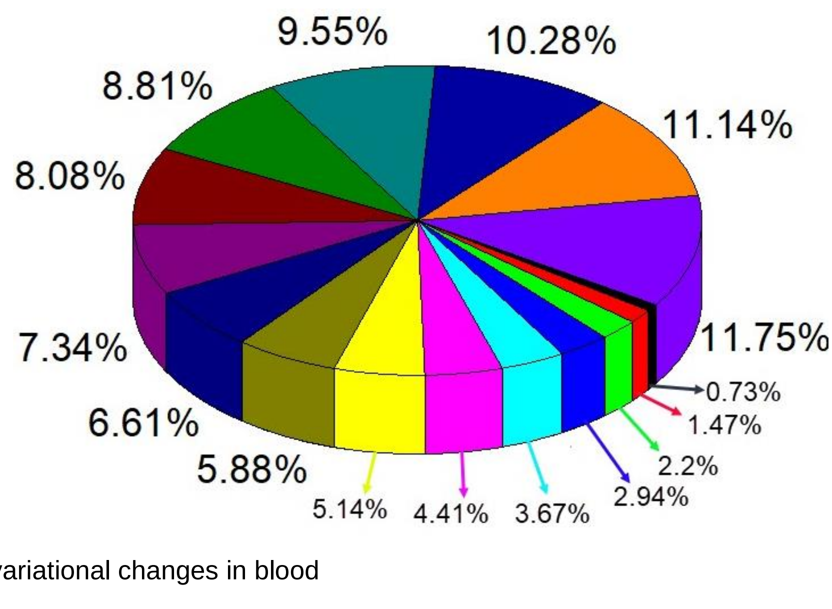

Fig.9. Percentage variational changes in blood velocity

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