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COMPARACIÓN DE MODELOS BDI EN SANGRE POR SIMULACIÓN CFD

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Resumen

La función del corazón es bombear la sangre en un circuito cerrado a los pulmones, donde la sangre se oxigena y va al cuerpo. El flujo es controlado por válvulas que están diseñadas para que solo circule el flujo de sangre hacia un solo sentido. Las cuatro válvulas permiten el flujo libre de sangre pero cuando ese flujo es obstruido puede ser un síntoma de una enfermedad de la válvula de corazón. La solución para la enfermedad de la válvula de corazón, hoy en día es el implante de una válvula protésica para sustituir la válvula natural de corazón. En los válvulas prostéticas del corazón típicamente de ocurre en fenómeno de daño de sangre. En daño de sangre de puede clasificar en dos, que son Trombosis que es la formación de coágulos en el sistema circulatorio y Hemolisis que es el daño de las glóbulo rojo. Para clasificar el daño de sangre que está ocurriendo en las prótesis se utilizan indeces de daño de sangre (BDI). Se investigó sobre los varios modelos de BDI y las condiciones en las cuales se aplica cada una, se utilizó las condiciones de frontera aplicados en trabajos previos de otros autores. Se utilizó un software de volumen finito (CFD) para simular velocidad de cizallamiento y el esfuerzo cortante para el caso analizado. Los resultados de la simulación se utilizaron para analizar y determinar el BDI adecuado, con ello se concluyó el tipo de daño de sangre que se tiene en el caso analizado.

Abstract

The function of the heart is to circulate the blood in a closed circuit to the lungs, where the blood is oxygenated and goes to the body as fuel for the cellular metabolism. The flow is controlled by valves that are designed to let blood flow in one direction. The four valves allow the free flow of blood to the body but when that flow is obstructed it may be a symptom of a heart valve disease. Thesolution today for the heart valve disease is implantation of a prosthetic heart valve to replace the natural heart valve. In the prosthetic heart valve a phenomenon usually occurs that damages the blood. Blood damage can be classified into two, which are Thrombosis which is the formation of clots in the circulatory system and Hemolysis which is the damaging of the red blood cells.To classify the blood damage that is occurring the blood damage index models were used. Many blood damage indexes were investigated and the condition in which they each apply. Using a volume finite software the case in a previous journal was simulated. The case was simulated so has to obtain the shear rate and the shear stress of the case. The results of the simulation were analyzed and placed in the BDI that fits the case. This helped us to obtain the type of blood damage that was occurring

Palabras Clave Válvula 1; Prótesis 2;Corazón 3; Índices de daño 4; Volumen finito 5

INTRODUCTION

Heart disease is something that has been one of the main causes of deaths in Mexico. The heart disease that has a solution that is connected to engineering theories is heart valve disease. The solution for this disease is replacing the natural heart valve with a prosthetic one. Replacing the natural heart valve has been a solution that has been practice for year but during the year this solution has had some important changes because of the side effect it has. By introducing a foreign body in the cardiovascular system the blood then to react different on the surface of this body. The foreign body usually damages the blood. The cardio vascular system can function effectively with some damage but this depend on the person. This study was made so has to determine the difference in the blood damage indexes so has to determine the adequate model for the determination of an adequate prosthetic design

Heart Valve

The heart valve diseases are classified in two types which are aortic stenosis with is when the heart valve does not open correctly and vulvar insufficiency which when the heart valve does not close correctly. The solution for these diseases until this day is the complete heart valve replacement which is classified in two. The two different types of heart value are mechanical and biological.

Blood damage

The blood damage is classified in two different types which are thrombosis and hemolysis. Thrombosis is the formationlf clot in the cardiovascular system due to the shear stress that is caused by the prosthesis. Hemolysis is the damaging of the red blood cell due to the shear stress that is presented in the cardiovascular system.

The thrombosis and hemolysis process are very complicated to understand but even so they have found mathematical model to help understand these process.

Thrombosis Model

In previous studies is has shown that the platelets coagulate when exposed to high shear stress. At high shear stress the activation of platelets occur. Hubbell and McIntire found out with the help of experiments that the maximum clot formation on polyurethane occurs at a shear rate of 500 s^{-1}. To contribute to this supposition Balasubramamian found out whit experiments that the blood coagulates occurs at 500 s^{-1} in three different polymers and silicone rubbers.
Based on previous experiments Giersiepen developed a power law curve to fit the model for platelet activation. Abrahamic used the power law using it as a different perspective and he came out with a model similar to Giersiepen power law the different is that is uses multiple shear stress by the time exposed to the shear stress.

Hemolysis Model

The red blood cells have a lifespan of 120 days. The premature damage of the red blood cells is known has Hemolysis. Hemolysis occurs when a mechanical assist device is places in the cardio vascular system and exposes the red blood cell to high mechanical stresses. Excessive Hemolysis can lead to anemia and a toxic level of plasma-free hemoglobin with lead to organ failure. Baldwin concluded that an exposer of 10,000 dyn/cm2on a time on 10ms as well 100s of exposer of 1,500 dyn/cm2 can damage the red blood cell. So he concluded that a shear stress of 1,500 – 4,000 dyn/cm2 were very undesirable. Also shear rate above 10s^{-1} stretches the membrane that releases the hemoglobin. With a shear rate of 42,000 s^{-1} the hemolysis is catastrophic that it can even cause's death.

With previous studies Giersipen used the same power law the got for thrombosis but with difference are the constants and the use of the Von Mises criterion to determine the blood damage done by hemolysis. Grigioni used Giesipen power law to make a model that uses the blood history with the derivative of time.

MATERIAL AND METHODS

The material used to make the study were a computer capable enough to run simulation. A computer fluid dynamic (CFD) was used to obtain all the valves that were needed to substitute in the adequate blood damage index (BDI) model.

The methodology that was used to solve the problem was one of investigation and simulation. A thorough investigation was made on the subject of inters. The document that were used were cardiovascular books and scholarly journals so has to keep the bibliography adequate for the studies made. Using a CFD software a case that satisfy the study was modeled. The modeling of the case include the modeling of a set of veins with certain characteristics also the modeling of the fluids, which is blood, which would be flowing through the veins model.

The results of the case simulated on the CDF software were analyzed to determine the adequate BDI to be used to determine the blood damage of the case. They are different BDI model, what determines the model used is the shear rate and the stress that the case gave us has result. The models that were obtained for thrombosis are the following:

$$\frac{\Delta LDH}{LDH}(\%) = 3.31 \times 10^{-6}\ t^{0.77}\ \sigma^{3.075}. \qquad (1)$$

Equation 1. Relates the percentage of activation of platelets during an exposed time.Shear stress (σ), time exposed *(t)*.

$$LOA = \sum_{path} \sigma_n \cdot \Delta t^{0.453}. \qquad (2)$$

Equation 2. Relates the percentage of activation of platelets during an exposed time at certain path. Von Mises (Sn), time exposed*(t)*.

Hemolysismodels

$$D = \frac{\Delta Hb}{Hb} = C\ \sigma_v^a\ t^b$$

Equation 3. Relates the percentage of red blood cells damage during an exposed time. Shear Stress (σ_v), time exposed *(t)*. C=3.62 x 10^{-6}, a=2.416, b=0.785

$$D = d\left(\frac{\Delta Hb}{Hb}\right) = a \times C \times \sigma_v^{a-1} \times t^b\ dt.$$

Equation 3. Relates the percentage of activation of platelets during an exposed time at certain path. Von Misses (σ_v), time exposed *(t)*. C=1.8 x 10^{-6}, a=1.991, b=0.765

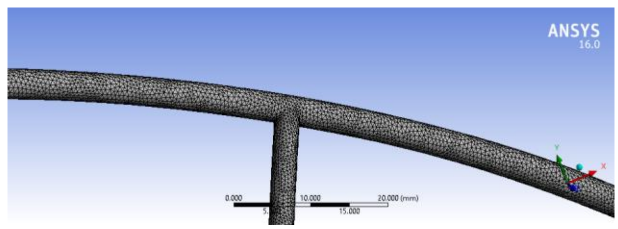

IMAGE 1: Shows the details of outlet 1

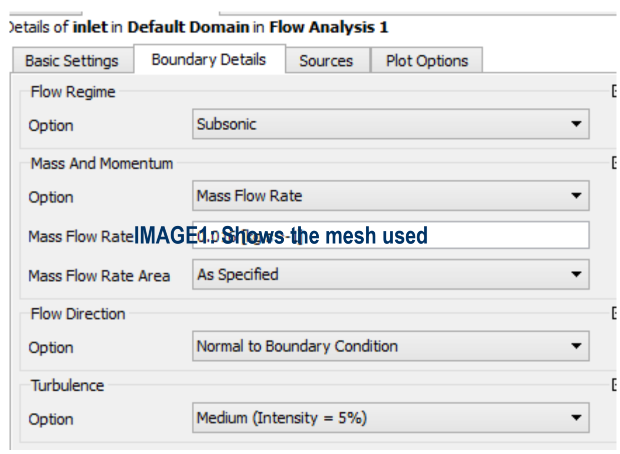

IMAGE1: Shows the mesh used

TABLE 2: Shows the red blood cell damage ratio done in various times

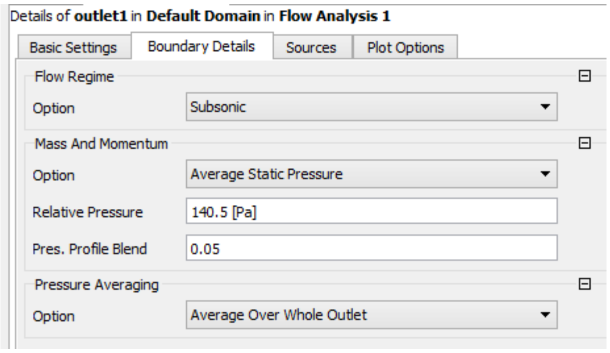

IMAGE 3: Shows the details of outlet 2

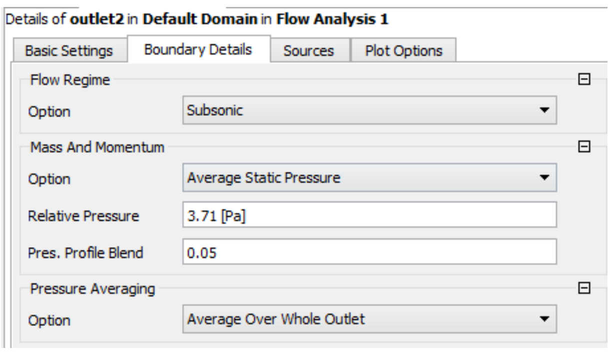

IMAGE 4: Shows the velocity of the blood flow

The inlet and outlet detail were taken from a previous article. The made a study on the cardiovascular system of a sixty year old man.

RESULT AND DISCUSSION

Simulation Data:

Diameter Inlet: 0.005m

Diameter Outlet 1: 0.00375 m

Diameter Outlet 2: 0.00325 m

Inlet Flow: 0.016 kg/s

Outlet pressure 1: 3.71 Pa

Outlet pressure 2: 140.2 Pa

Fluid Data:

Density: 1050 kg/m^3

Viscosity: 0.003528 Pa s

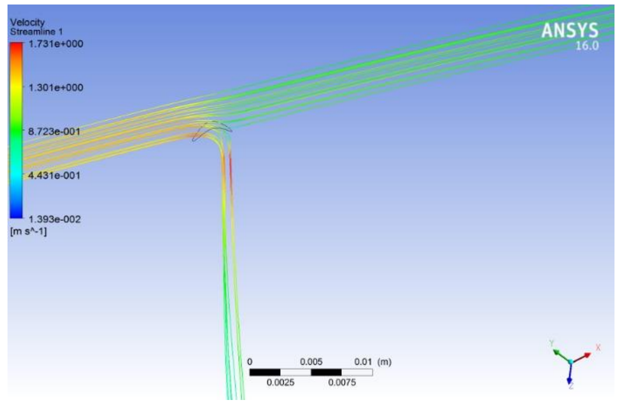

IMAGE 5: Shows the inlet details

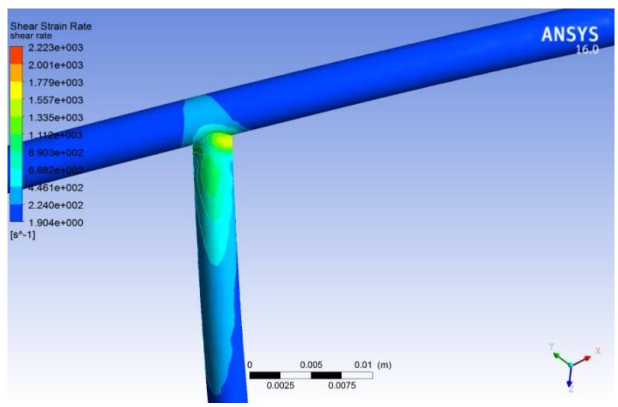

IMAGE 6: Shows the wall shear to determine the BDI

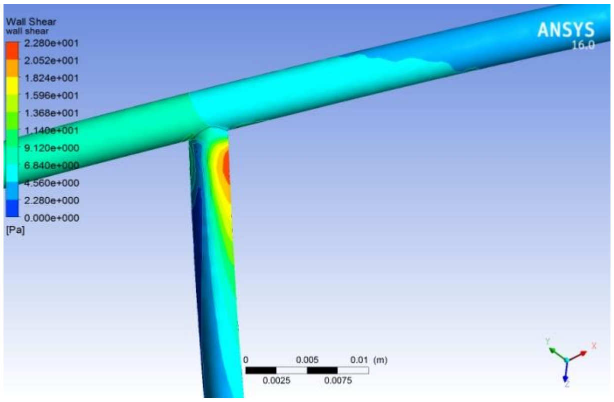

TABLE 7: Shows the shear rate to determine the blood damage

TIME (S)	DAMAGE RATIO
0	0.00000
0.1	0.00113
0.2	0.00195
0.3	0.00269
0.4	0.00337
0.5	0.00401
0.6	0.00463
0.7	0.00522
0.8	0.00580
0.9	0.00636
1	0.00691

The fluids data is the one of a 60 year old man without a history of heart problems. The condition is normal for a person of that age. The blood was analyzed in those time because of the pulsating motion of the Heart, the normal beats per minuteis 60-100 pbm. Even thought that the blood achives the maximum velocity at the 44 percent of the time of the beat analysis was completely.

CONCLUSIONS

The simulation gave us the facility to analyze the blood damage in a particular case with you the experimentation on person. This will help us to simulate the blood damage that is made on a prosthetic heart valve and help optimize the design. According to the findings of the research and the simulation results of the case study, the vein had fallen in the cases on hemolysis. The Shear rate value was of 1.557 x 10^3 s^{-1} which lets it fall in the case of hemolysis. The BDI that would best fit this case is the Giersipen Hemolysis Blood model. The blood model was analyzed using shear stress of 22.8 Pa and it shows a ratio of red blood cell damage ratio of 0.00691. This Damage is occurs at the maximum velocity of 20 cm/s.

ACCREDITATIONS

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