N. S. Mahmoud
Mechanical Engineering Dept.
University of Technology
Baghdad, Iraq
20073@uotechnology.edu.iq

A.A. Al-allaq
Ministry of High Education and Scientific Research, Office Reconstruction and Projects
Baghdad, Iraq
ali_martial85@yahoo.com

Received on: 18/05/2016
Accepted on: 29/12/2016

Numerical Study of the Effects of Aneurysm and Stenosis in the Left Coronary Artery on the Human Blood Stream

Abstract*-The heart is the most important muscular organ in human's body, which pumps blood through the arteries to supply the body with oxygen and nutrients. The heart is supplied by the coronary blood vessel; therefore, the effect of aneurysm and stenosis in left coronary artery on the velocity of blood, wall shear stress of artery and mass flow rate of blood have been investigated in this study. The simulation program (ANSYS Fluent) was used to execute the numerical study. Typical geometry of left coronary artery and physiological parameters of human blood values were obtained from measured values reported in literature. The problem of the effect of the aneurysm and stenosis on the human blood stream has been solved numerically under three conditions, healthy artery and two infected cases (30%, 50%) percentage of aneurysm in left main stem (LMS) and stenosis in left anterior descending (LAD). It has been shown, in stenosis region that the velocity of blood will suffer fast flowing and an increase in the shear stress on the artery wall, in contrast with the aneurysm case, blood velocity becomes slow and low wall shear stress. Also irregularity was shown in mass flow rate of blood in the left coronary artery which suffers from aneurysm and stenosis compared with healthy artery.*

Keywords*- Aneurysm; blood velocity; coronary artery disease; CFD , mass flow rate; stenosis; wall shear stress.*

How to cite this article: N.S Sameer, and A.A. Al-allaq, "Numerical study of the effects of aneurysm and stenosis in the left coronary artery on the human blood stream," *Engineering and Technology Journal*, Vol. 35, Part A, No. 1, pp. 29-40, 2017.

1. Introduction

The heart is the only organ in charge of the blood pumping and piped to the rest of the organ of the body, so it is essential to the continuation of the work and feeding the heart muscle in order to continue the sustainability of life, the heart muscle, like other organ or tissue in the human body, needs to nourishment by oxygen-rich blood to keep alive. Blood is supplied to the heart by coronary circulation. The vessels that transmit oxygen-rich blood to the heart muscle are known as coronary arteries. These arteries when healthy are capable to maintain coronary blood flow at levels convenient to the needs of the heart muscle. Abnormal wall thickness of the coronary artery, known as atherosclerosis, is a cumulative disease that can lead to narrowing internal luminal of artery, resulting in a decrease of blood flow and produce ischemia [1]. Many questions concerning the pathogenesis of atherosclerosis remain unanswered. Various factors, such as heredity, dietary fat content, hypertension, obesity, diabetes, and smoking, are believed to aggravate the disease [2].

The other abnormal case that afflicts coronary artery called artery aneurysm. Which is defined as a coronary dilation that exceeds the diameter of normal adjacent segments or 1.5 times the diameter of the patient's largest coronary vessel, may perform the common reason of death because of irregular blood flow within the aneurysm may lead to embolization, occlusion, thrombus formation, myocardial infarction, or myocardial ischemia [3].

Coronary artery aneurysm is attributed to atherosclerosis in 50% of cases, whereas 20-30% have been considered to be congenital in origin, only 10% to 20% of cases of coronary artery aneurysm have been described in association with inflammatory or connective tissue diseases [4]. The patients with aneurysms of coronary artery usually exist with edema, angina pectoris, dyspnea, or sudden death, the patient's diagnosis with coronary artery aneurysms related with the coronary atherosclerosis is not different than the patient's diagnosis with coronary atherosclerosis without aneurysms [3].

Multiple medical studies and research indicate that the stenosis and aneurysm of the coronary arteries in some cases are present in the same patient especially when the patient is infected with Behcet's disease.

https://doi.org/10.30684/etj.2017.127308
2412-0758/University of Technology-Iraq, Baghdad, Iraq

Sonia et al [5] presented a case of a patient with Behcet's disease with developed coronary artery aneurysm and stenosis, the coronary angiography of selected patient, manifests one aneurysm on the distal right coronary artery with a strong occlusion existing on the proximal part of the posterolateral branch.

Zeb et al. [6] Searched on the case of patient with a coronary artery aneurysms in the proximal dominant right coronary artery followed by severe stenotic disease, there was moderate to severe disease within the proximal left anterior descending (LAD) and circumflex coronary arteries (LCX).

Also, Sofia et al. [7] have investigated the rare case of Behcet's disease, when diagnosis patients, the coronary angiogram showed huge aneurysm of (LAD) followed by tight stenosis in different cranial angulations before angioplasty.

All of submitted literature proved the occurrence of aneurysm and stenosis in the same coronary artery. Therefore, the idea of this research is to analyze this case from an engineering point of view and compare it with normal case. Due to the importance of this subject, it was decided to look on many specialist researches simulated blood flow in the coronary artery and represent the pathological case.

Chichana et al. [8] studied the variations effect of the left coronary artery angles, based on realistic and simulated coronary artery cases, (12) cases consisting of (4) realistic and (8) simulated coronary artery geometries were generated with the existing of the left main stem (LMS), (LAD) and (LCX). The results of this research showed that a troubled flow behavior was watched in models with wider angle, and wall pressure was observed to decrease when the flow changed from the (LMS) to the bifurcated areas.

Chichana et al. [9] studied the computational fluid dynamics analysis at left coronary artery to simulate realistic physiological conditions that reflect the in vivo (within the living body). This research proved that the highest-pressure gradient was found in stenosis area caused by the plaque of artery. The low flow velocity regions were observed at post plaque areas in the (LCX), (LAD), and bifurcation region.

Moreno et al. [10] presented a study related to the stenosis of coronary artery and inclusion plaque on blood flow .They performed this study depending on their previous research, that classifies the coronary plaques of forty two patients into four types after diagnosis by intravascular ultrasound. This research numerically simulated coronary artery blood flow and investigated wall shear stress, turbulence existence and transition region from laminar to turbulence flow are further hemodynamics parameters to distinguish plaques vulnerable to rupture.

Frattolin et al. [1] investigated the effect of stenosis acuteness and place in coronary artery side branch numerically to study the flow pattern of the stenosis in the side branch of the lesion bifurcation. The outcomes of this study explained that the existence and relative area of bifurcation lesions in coronary artery created a serious effect on the flow and WSS distribution in the side branch.

Previously mentioned engineering research did not indicate the existence of stenosis and aneurysm in the same patient that has coronary artery disease. This research will be focused on a representation of the blood flow in the left coronary artery. Anatomically, the left coronary artery consists of left main stem (LMS) and bifurcates to (LAD) and (LCX). The existence of aneurysm in the (LMS) and stenosis in the (LAD) was studied. The basis of the representation of this situation is existed in Behcet's disease and some of the diseases mentioned cases as in Ref. [11].

2. Materials and Numerical Method

I. Geometrical Model

The importance of left coronary artery is nutrition blood to the left part of the heart, the left atrium and ventricle. This leads to attention of a lot of researchers; Douglas et al. [12] presented the evaluation of two-dimensional echocardiographic visualization of coronary artery anatomy in the adult and investigated the average length and diameter of left main coronary artery and its branches (LAD) and (LCX). Also, Waller et al. [13] focused on the anatomic aspects of the epicardial coronary artery system, coronary arterial distribution, myocardial supply, and histological features of the normal coronary artery. In this research, the selected dimensions were based on the previous mention researches [8,12and13]. The lengths of LM, LAD and LCX are (35 mm, 25 mm, 20 mm) and diameters are (3 mm, 2 mm, 1.5 mm) respectively. The angle between LAD and LCX is taken as (75^o). Figure 1 shows the anatomy details of the left coronary artery with bifurcation in to (LAD) (LCX) branches. In the studied abnormal cases, the aneurysm length (7 mm, 20% of the length of LMS) and the dilatation in diameter studied were (3.9 mm, 4.5 mm) corresponds to 30% and 50 % of diameter of (LMS). Also in stenosis case, the length of stenosis were (5 mm, 20% of the length of LAD) and stenosis diameter (1.4 mm, 1 mm) which represent 30% and 50 % of the diameter of LAD ,as shown in Figures 2 (a ,b ,c).

II. Physiological boundary conditions

To ensure that the current investigation reflects the factual simulation as in vivo situations, physiologically realistic boundary conditions were applied by using hemodynamic rheological and material properties, depending on the previous studies.

The behavior of blood in vessels smaller than approximately 100 μm exhibits significant non-Newtonian effects, flow in larger vessels can be described with reasonable accuracy using the Newtonian assumption. In Computational fluid dynamics simulations, the blood was assumed to be Newtonian with constant viscosity of (0.0035 pa. s) and blood density (1060 kg/m^3) as presented in [8,9].

Since the velocity and pressure of blood flow in the (LMS) of coronary artery has an effect on the estimate results of the study. So, it was selected to determine the actual parameters in the coronary arteries that are close to reality, the value of velocity was (33 cm/sec) and pressure (100 mmHg) as average at the inlet of the artery [15-17].

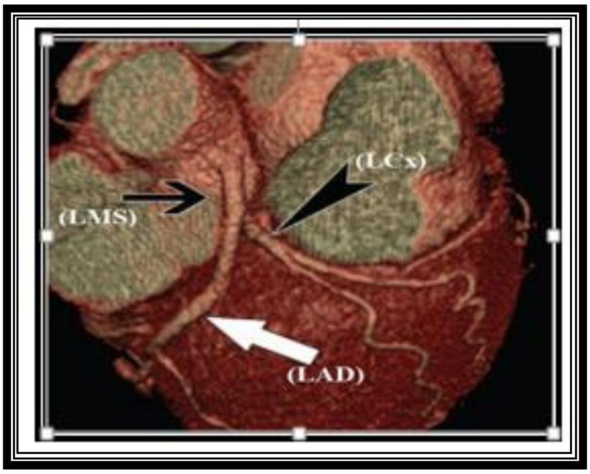

Figure 1: Volume rendering (VR) image technique of the left coronary artery branches [14].

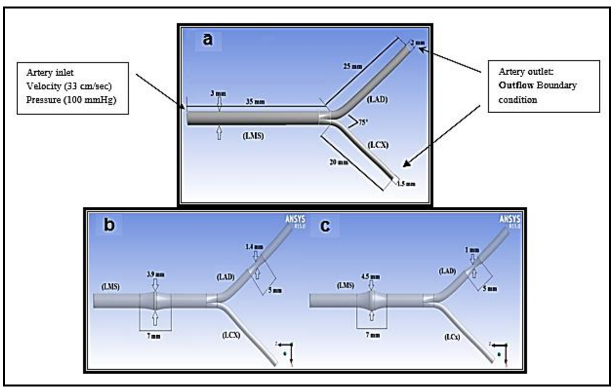

Figure 2: Drawing of (LMS) bifurcating into (LCX) and (LAD) (a) healthy, (b) 30% stenosis and aneurysm, and (c) 50% stenosis and aneurysm

III. Numerical methods

Full 3D model of the left coronary artery was generated using (Solid Works software version 2014), as in Figure 2, which represents a volume of the blood flowing through the artery, i.e. boundary walls of the model are internal walls of the blood vessels. To obtain a solution of the problem described, the (ANSYS Fluent code version 15.0) was used. According to the ANSYS Fluent Theory Guide, the problem is simulated by solving the conservation equations of mass Eq. (1), and momentum Eq. (2), [18]

$$\Delta \cdot v = 0 \qquad (1)$$

$$\nabla \cdot P - \rho \Delta \cdot v = 0 \qquad (2)$$

Where (v) is the velocity vector, (P) is the pressure and (ρ) is the density.

Blood flows observed in real anastomoses are usually turbulent, therefore the turbulent (Realizable k-ε model) was used in this study, equations (3) and (4), [19]:

$$\frac{\partial}{\partial x_j}\left(\rho k u_j\right) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k - \rho_\varepsilon \qquad (3)$$

$$\frac{\partial}{\partial x_j}\left(\rho \varepsilon u_j\right) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial \varepsilon}{\partial x_j}\right] - \rho C_2 \frac{\varepsilon^2}{k+\sqrt{v\varepsilon}} \qquad (4)$$

Where k is the turbulent kinetic energy, (ε) is the dissipation rate and the other parameters were described in Ref. [19].

A mesh independence test was carried out depending on the mass flow and velocity of blood using three grid sizes (500,000-750,000 and 1000,000) of tetrahedral elements, this leads to the selection of mesh size of (1000,000) concentrated near the wall where high velocity gradient was expected.

3. Results

The influences of stenosis and aneurysm on blood velocity, blood flow rate and wall shear stress WSS in the left coronary artery were investigated by ANSYS Simulations program. For accuracy of the description and understanding of what is happening inside the artery under various pathological conditions of the left coronary artery the velocity studied on six different axial locations along the length of the artery. The section locations are selected correspond to the existence of pathological cases in these positions and compare them with same location in the healthy artery. Two section lines in the main stem of left coronary artery at (S1=17.5 mm, S2=13mm) above bifurcation point which is considered as origin point.

In the (LAD) three sections are selected (30 %, 50 %) of stenosis and healthy case, the first section before stenosis area at (S3=10 mm), the second in the stenosis area at (S4=12.5 mm), and third one after stenosis area at (S5=17.3 mm), and in (LCX) (S6) at (12 mm) down of bifircation point as shown in Figure (3) (a, b, c). The obtained results demonstrate the variation of velocity in section (S1, S2), shown in Figure (4) (a, b) and Figure (5) (a, b).

The stenosis effect on blood velocity at (LAD) and the change that is happening in typical distribution profile of blood velocity in the artery at sections (S3, S4, S5), shown in Figure (6) (a, b) and Figure (7) (a, b, c).

Figure (8) show the effect of both aneurysm in (LMS) and stenosis in (LAD) on the blood velocity in (LCX) and also show the change that happens in ideal blood velocity in healthy artery.

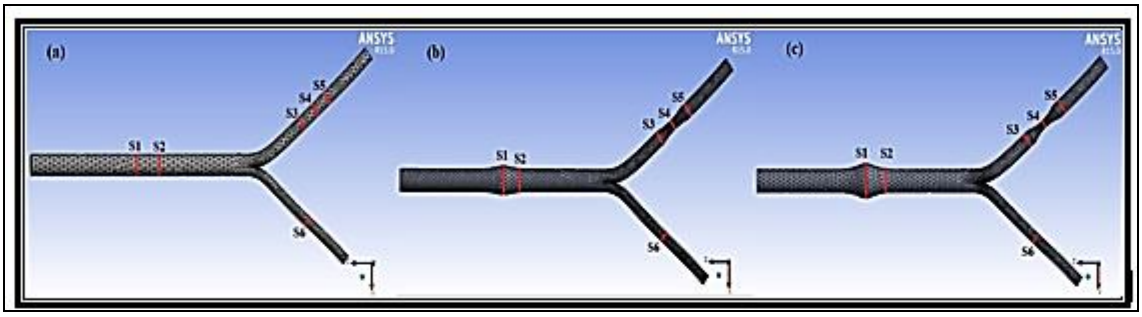

Figure 3: The section lines for (a) healthy case, (b) 30% stenosis and aneurysm case, (c) 50% stenosis and aneurysm case

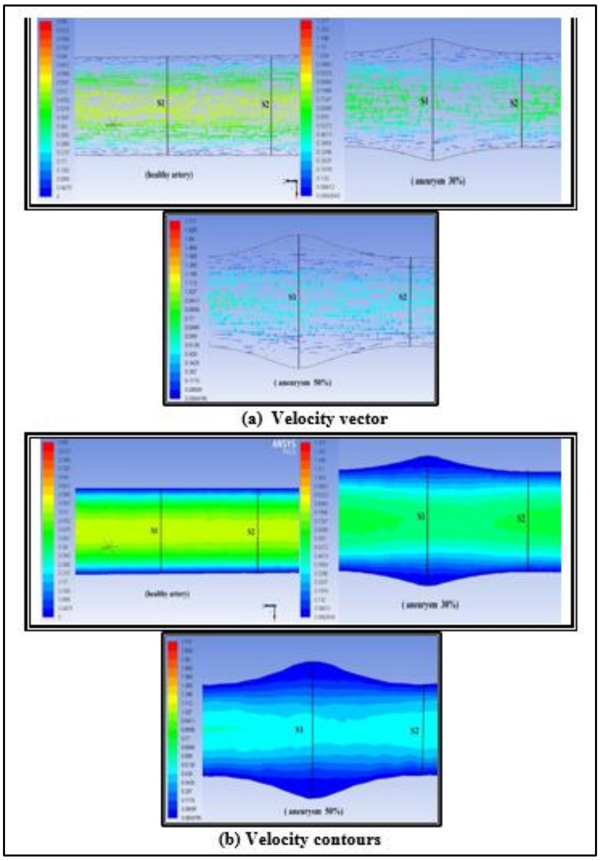

Figure 4: The variation of velocity at (S1 and S2) sections in main stem of left coronary artery for (30% , 50%) of aneurysm and compare with healthy case.

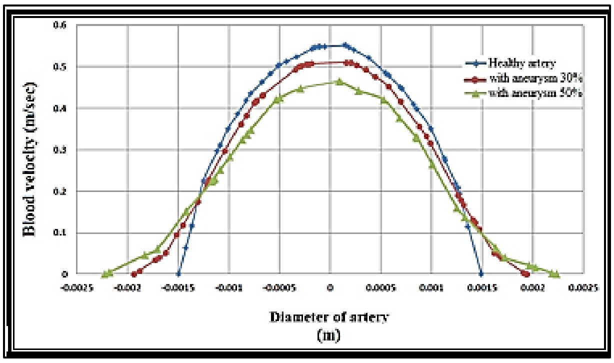

Figure 5a: The variation of velocity at section (S1) in main stem of left coronary artery for (30% , 50%) of aneurysm and compared with healthy case.

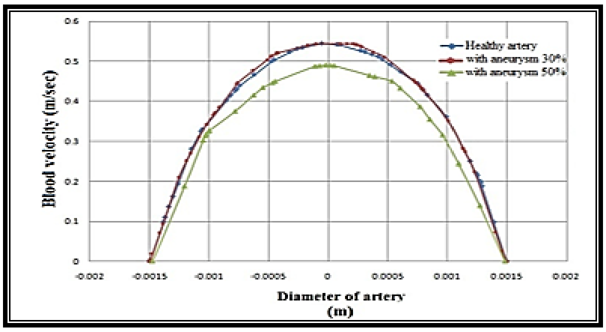

Figure 5b: The variation of velocity at section (S2) in main stem of left coronary artery for (30% , 50%) of aneurysm and compared with healthy case.

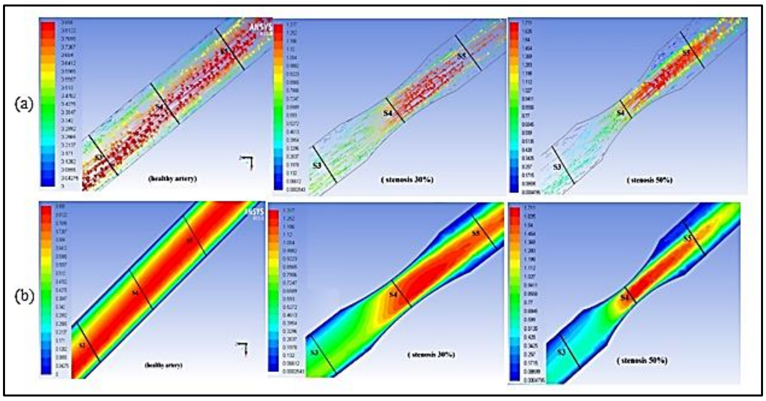

Figure 6: The variation of velocity at (s3, s4 and s5) sections in (LAD) for (30% , 50%) of stenosis and compare with healthy case (a) velocity vector (b) velocity contours.

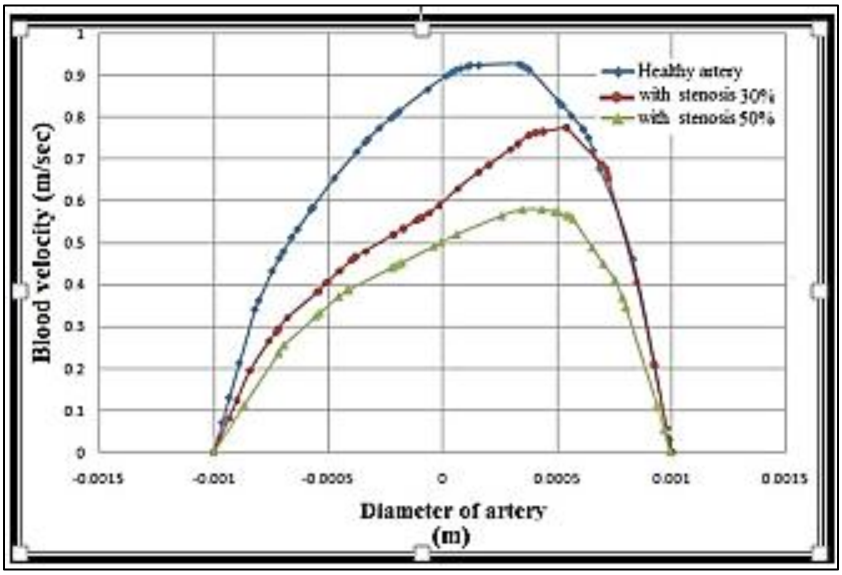

Figure 7a: The variation of velocity at (s3) section in the (LAD) for (30% , 50%) of stenosis and compare with healthy case.

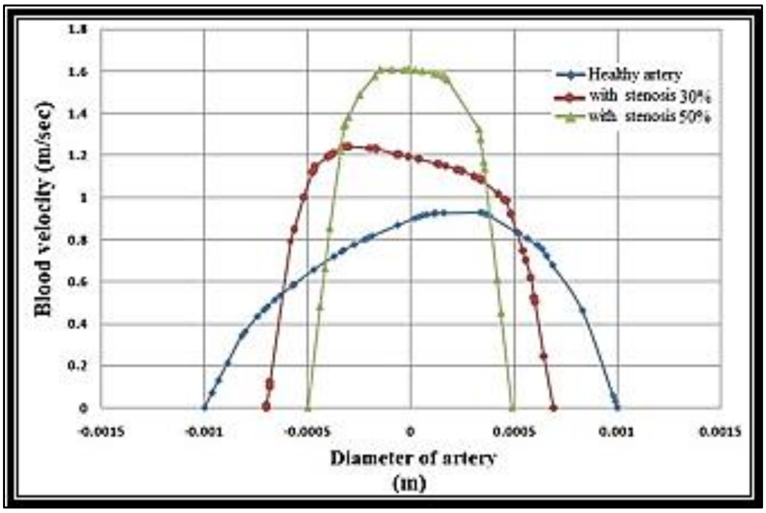

Figure 7b: The variation of velocity at (s4) section in the (LAD) for (30% , 50%) of stenosis and compare with healthy case.

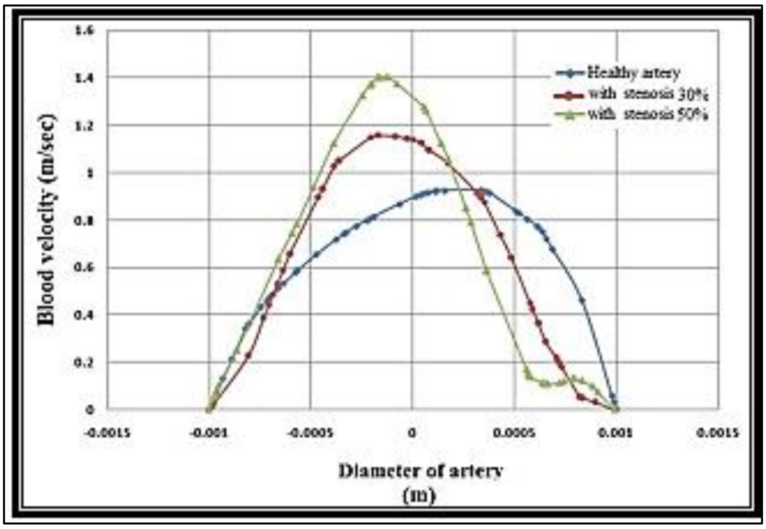

Figure 7c: The variation of velocity at (s5) section in the (LAD) for (30% , 50%) of stenosis and compare with healthy case.

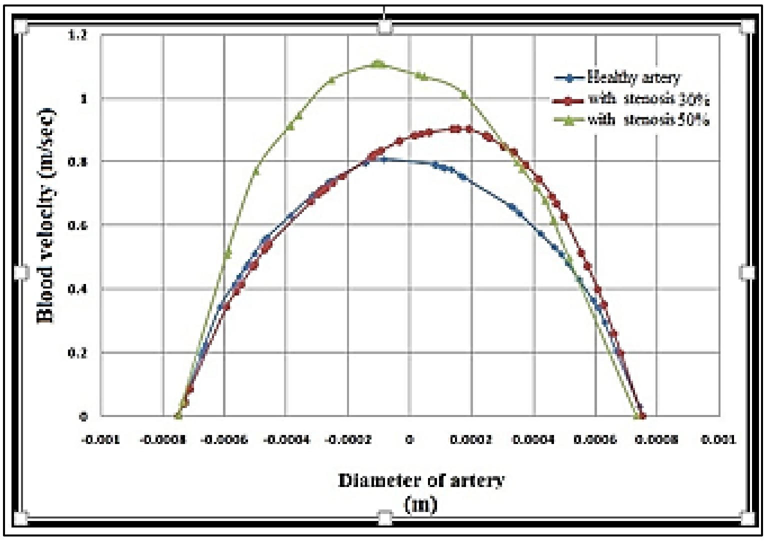

Figure 8: The variation of velocity at (s6) section in the (LCX) for studied disease cases and compared with healthy case with healthy case.

The effect of stenosis and aneurysm for different incidence on (WSS) wall shear stress distribution and magnitude was investigated. Wall shear stress (WSS) on the artery wall is the force with tangential direction generated by blood flow across endothelial side. The variation value of WSS depends on velocity gradient of blood near the endothelial side of artery [20]. Endothelial is the tissue lining inner of blood vessels. To explain the divergence of WSS for different locations, on the healthy and infected artery, WSS was computed along the inner wall of the artery at three longitudinal lines (WSS1, WSS2, and WSS3) on the (LMS), (LAD) and (LCX) respectively. Also, the locations was selected to coincide with the presence of pathological cases in this site and compared with the same location for healthy artery as shown in Figure 9. The obtained results show the variation of WSS for the studied cases at the selected locations on the artery as shown in Figures 10, 11 and 12.

Mass flow rate of blood is defined as the mass of blood passes per unit time. The inlet to (LMS) artery is the blood comes from the aorta passes through it and then split to flow in (LAD) and (LCX) arteries. It is necessary to know the amount of blood that flow in the coronary artery with stenosis and aneurysm case. The blood mass flow rate in the coronary artery in the three studied cases have been analyzed and the effects of artery stenosis and aneurysm with different percentage of lesion were found and compared with healthy condition, as shown in Figure 13.

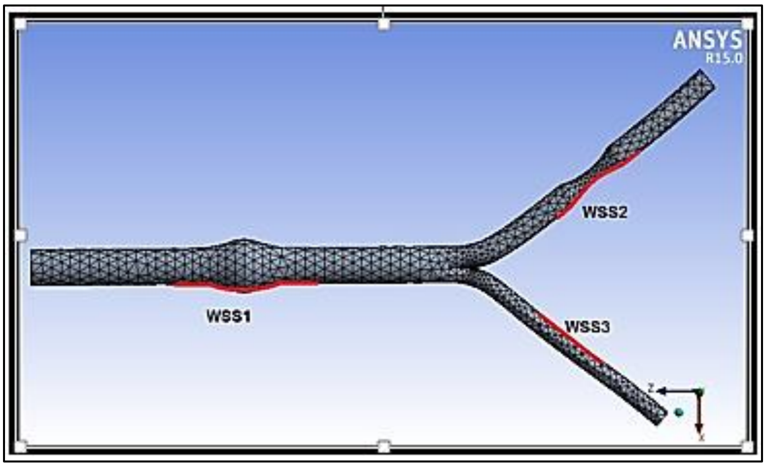

Figure 9: Locations of WSS in left coronary artery and its two branches

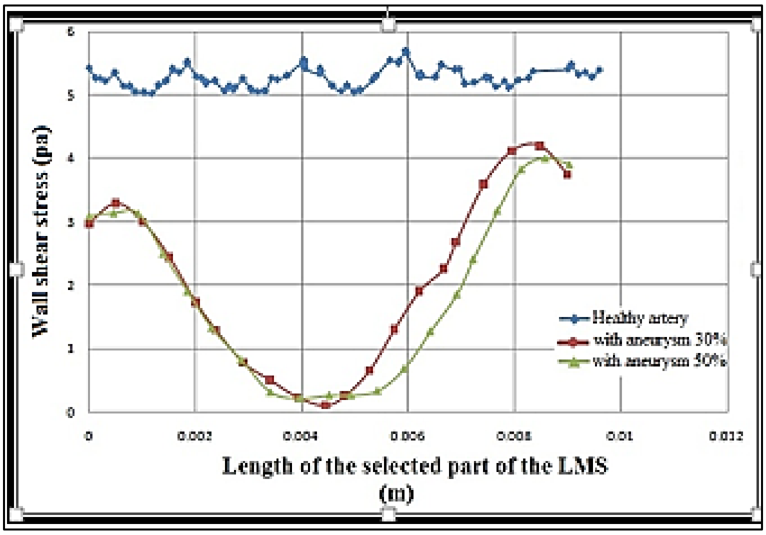

Figure 10: The variation of WSS along the longitudinal section of (LMS) for different disease cases and compared with healthy cases.

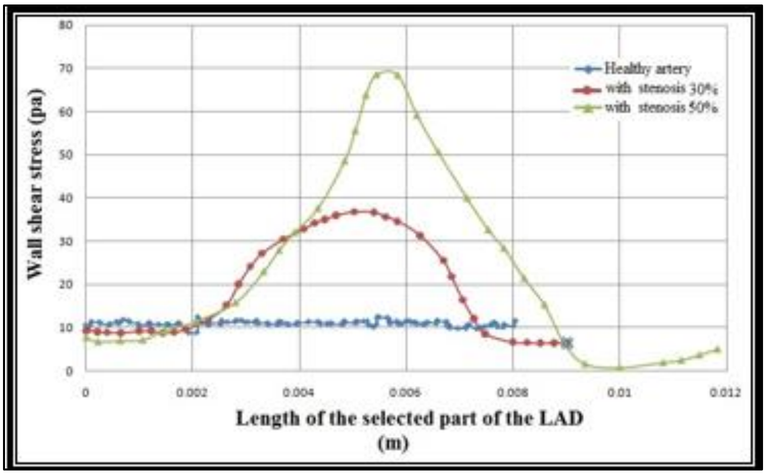

Figure 11: The variation of WSS along the longitudinal section of (LAD) for different disease cases and compared with healthy cases.

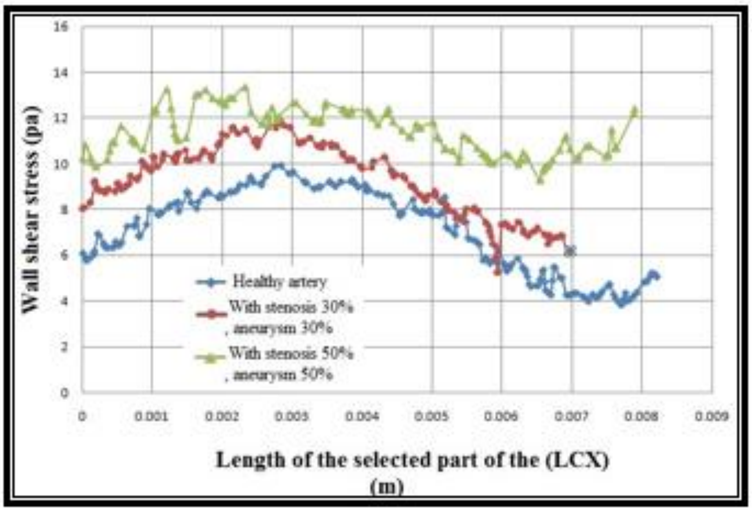

Figure 12: The variation of WSS along the longitudinal section of (LCX) for different disease cases and compare with healthy cases.

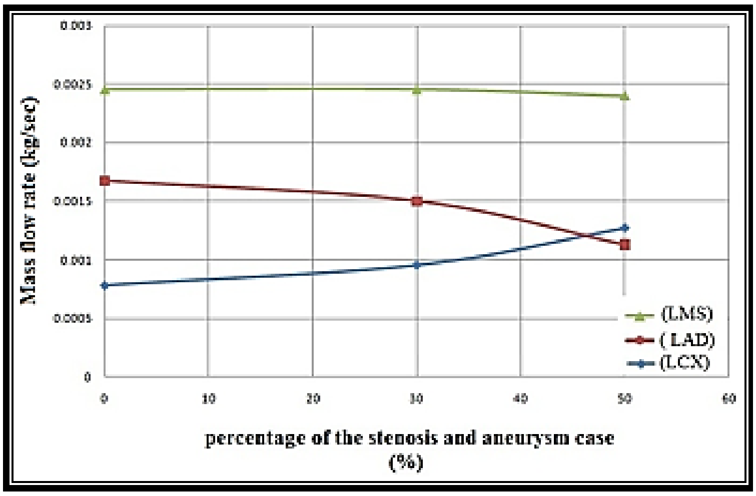

Figure 13: The variation of the mass flow rate of blood in left coronary artery with two branches for three cases studied (healthy condition, 30% stenosis and aneurysm and 50% stenosis and aneurysm)

4. Discussion

The conducted analyses reflects the impact of the coronary artery disease on the velocity of blood, blood flow rates and shear stress on the artery wall which is very important and difficult to study in vivo. For this purpose, the need for a numerical study emerges, and the selection of physiological parameters for a good estimation to get the best analysis results.

The velocity of blood is the rate at which blood flows in a blood vessel. If the flow is constant, the velocity has an inverse relation with the cross section of blood vessel. The velocity of blood depends on force of heart action, peripheral resistnce of blood vessel [21]. Cross section of coronary artery is related to regional myocardial mass [22], age, sex, anatomic variation, and left ventricular hypertrophy or dilation [23]. In addition, pathological case such as aneurysm (increase in the size of the artery diameter) and stenosis (decrease in the size of the artery diameter).

The Figures 5(a,b) illustrate the effect of aneurysm in (LMS) on the blood velocity. This is a reasonable effect because the vessel diameter directly influences on the velocity. The blood velocity in vessels commonly reduces with increased diameter of lumen. The reason for this is that blood flow equals the product of mean velocity times cross sectional area which is proportional to the squared radius, so the blood velocity at constant flow is inversely proportional to the squared diameter of artery [24].

Blood velocity in all Figures as shown is faster in the center of the artery. When blood flows through a long, smooth wall vessel, it does so in layers. The velocity of the layer varies with blood in the center moving much faster than blood in the outer layers because it is in contact with blood only. The outer layer is also in contact with the intima (inner layer of blood vessel wall), which exerts friction against the cellular component of the blood [25].

Deformation of vessel wall may lead to turbulence. For example, in varicose veins or aneurysm there is a local increase in the lumen of vessel which leads to eddies formation [26]. Turbulence in blood flow increases the require energy to force blood because it increases the energy loss due to friction with artery wall, which produces heat [24].

As in the anatomic reality, the (LMS) bifurcates in to (LAD) and (LCX). District bifurcation of artery has a role in changing the style and velocity of blood flow at stated branches as shown in Figures 6 and 7. At the bifurcation where there is abrupt change in direction of flow, local pressure gradients develop, and the velocity profile becomes skewed with higher velocities toward the central flow divider [27].

The value of wall shear stress depends on the rate of blood velocity increase when moving from the artery wall to the center of the artery. The velocity gradient is close to the artery wall is the wall shear rate for the artery [28].

Wall shear stress is calculated near the wall for the cylindrical tube as [20, 28].

$$\mathrm{WSS}=\frac{4\mu Q}{\pi r^3} \qquad (5)$$

Where μ viscosity of blood in (pa.sec), Q blood flow in (m^3/sec), and r radius in (m).

The value of wall shear stress is proportional directly to blood viscosity and flow and inversely proportional to the cube of the radius of the artery. So, the slight change in radius of artery will have a large impact on the wall shear stress [20, 28] as shown in Figures (10-12). Therefore, the effect of aneurysm and stenosis of coronary artery appears on the WSS whether in the region or beyond the affected area. The effect of aneurysm on the change of WSS from high to low shear stress in infected area caused by (30%,50%) enlargement as show in Figure 10. The region after aneurysm will suffer from a rise in WSS due to the decrease in radius of artery. The opposite of that take place in (LAD) infected by (30%, 50%) stenosis lead to increase in WSS. Due to the impact of the existing narrow of artery radius and increase in velocity of blood, subsequent to the stenosis area will suffer from low WSS because of expansion of artery diameter (radius of normal and healthy artery) as shown in Figure 11.

Shear stress has an immediate influence on the endothelial cells for artery wall, which in turn liberates nitric oxide as a reaction to the increase in shear stress, making relaxation for smooth muscle cells of artery wall and lead to vasodilatation [20]. Vasodilatation is expansion of blood vessels for increase blood nourishment to tissues that necessity it most.

Atherosclerosis is a disease of the arterial wall which appears to be strongly influenced by hemodynamics [15]. It is related with genetic capability and various risk factors such as diabetes mellitus, social stress, heavy smoking, hyperlipidemia, and hypertension. The effect of atherosclerosis is to make a weak hemodynamic shear stress due to blood flow slow and changes direction with the cardiac cycle [29]. High wall shear stress leads to increase in plaque formation by making endothelial injury and disturbance, so the artery wall expose to fats and circulating platelets [20].

As coronary arteries are responsible for the transfer of blood carries oxygen to the myocardium (means heart muscle, the muscle tissue of the heart that contained from thick contractile muscle cells in charge of contractile pumping). So, the amount of blood passing through the artery is important to know, especially in the pathological condition. Mass flow rate gives the amount of blood that passed through the unit time. Figure 13 shows the effect of bifircation large diameter (LMS) in to the smaller two branches (LAD) and (LCX) on the blood flow rate for the three studied cases (healthy, 30%, 50%). In the bifurcation of the arteries the main flow is divided into two separate flows, so its mass flow rate is divided. The flow rate is depending on the resistance to flow, so the diameter of artery and its alignment has important influence on the flow rate. However, the mass flow rate must be ensured and preserved throughout the whole branch network of the arteries [30].

The (LCX) branch, assumed in this research, healthy artery and have smaller diameter than (LAD) but, Figure 13 shows the mass flow rate of blood in (LCX) is high when stenosis exists in (LAD). This is because the amount of blood that inlet in the (LAD) will be few due to the presence of stenosis lesion, the residual blood will turn to the (LCX) and caused increased blood velocity in (LCX) when increase percentage of stenosis at (LAD) as shown in Figure 8.

The (LAD) is one of the important arteries in heart and considered the most critical vessel in terms of myocardial blood supply, the (LAD) passes around the apex of the heart to the enter the posterior interventricular groove and anastomoses with terminal branches of the right coronary artery. The (LAD) branch supplies the right and left ventricles with numerous branches that also supply the anterior part of ventricular septum [31]. When the blood supply passes through, (LAD) reduces, or vanishes that leads to health problems in parts that take nutrition from it.

For most of the people that suffer from coronary artery disease, the nutrition of oxygenated blood is decreased due to the progression of stenosis in the coronary arteries. In addition to plaque buildup, convulsions of the muscles that surround the coronary arteries can also cut off the blood supply. In (eighty-five) percent of people who have coronary artery spasms, atherosclerosis also exists. In about (ten to fifteen) percent of people with exemplary angina chest pains, spasms may be the alone reason of the ischemia and resulting pain [32]. Ischemia caused by dysfunction or damage of artery gives rise to limitation of blood nutrition and causing a deficiency of glucose and oxygen to remain tissues alive.

Myocardial ischemia is a case of the heart whereby oxygenated blood is incapable to be provided adequately. The heart tissue suffers from a shortage of oxygen supply, which affects in angina pectoris (chest pain from an ischemia) or leads to myocardial infarction (heart attack) and myocardial ischemia [30].

As previously stated, the aneurysm and stenosis coronary artery disease will affect in one way or another on the natural flow of blood in addition to the effect of the common profile of blood velocity. Therefore, an imbalance and scarcity in the amount of blood will reach in the heart muscle as a result of this disease case.

5. Conclusions

1- The aneurysm and stenosis is one of the diseases that suffered the human artery, especially coronary artery as a result of genetic conditions, aging, excessive eating and smoking.

2- Unbalance and change in the velocity profile of blood flow in the left coronary artery, which undergoes aneurysm and stenosis. The velocity of blood will turn from slow to fast-flowing in stenosis region. Vice versa in the aneurysm case, blood velocity becomes slow.

3- The wall shear stress is affected by the blood velocity so the increases of the artery stenosis degree lead to increase wall shear stress on the artery. Shear stress has a direct effect on the internal tissue in the artery lumens, which comply with increases in shear stress that caused the relaxation of artery wall smooth muscle and vasodilatation.

4- Disturbance and irregularity in the normal amount of blood that pass through the left coronary artery, which suffers from aneurysm and stenosis. Therefore, malfunction occurs in a heart muscle that is fed from this artery.

5- Insufficiency of the coronary arteries to provide blood supply to the heart muscle with stenosis existence can lead to myocardial infarction and ischemia.

References

[1] J. Frattolin, M.M. Zarandi, C. Pagiatakis, O.F. Bertrand, and R. Mongrain, "Numerical study of stenotic side branch hemodynamics in true bifurcation lesions," Computers in Biology and Medicine 57, pp.130–138, 2015.

[2] T. Asakura, and T. Karino "Flow Patterns and Spatial Distribution of Atherosclerotic Lesions in Human Coronary Arteries," Circulation Research Vol 66, No 4, pp.1045-1066, April 1990.

[3] L. Nichols, S. Lagana, and A. Parwani "Coronary Artery Aneurysm A Review and Hypothesis Regarding Etiology," Arch Pathol Lab Med,Vol 132 , pp.823-828, May 2008.

[4] S. Mavrogeni, "Coronary Artery Ectasia: From Diagnosis to Treatment," Hellenic J Cardiol. Vol. 51, pp. 158-163, 2010.

[5] H. Sonia, B.H. Khaldoun, M. Sylvia1, M. Faouzi, G. Habib, and B.F. Mohamed, "Stenosis and Aneurysm of Coronary Arteries in A Patient with Behcet's Disease," The Open Cardiovascular Medicine Journal, vol.2, pp.118-120, 2008.

[6] M. Zeb, D.B. McKenzie, P.A. Scott, and S. Talwar, "Treatment of Coronary Aneurysms with Covered Stents," J Invasive Cardiol, 24(9), pp.465-469, 2012.

[7] M. A. Soofi, A.B. Abdulhak, F. AlSamadi, A. Elasfar, and M. Youssef, "Stenting for huge coronary artery aneurysm and stenosis in a patient with Behcet's disease presenting with non-ST segment elevation myocardial infarction," Journal of Cardiology Cases 8 , pp.e3–e6, 2013.

[8] T. Chaichana, Z. Sun, and J. Jewkes, "Computation of hemodynamics in the left coronary artery with variable angulations," Journal of Biomechanics, Vol. 44, pp. 1869–1878, 2011.

[9] T. Chaichana, Z. Sun, and J. Jewkes, "Computational Fluid ynamics Analysis of the Effect of Plaques in the Left Coronary Artery," Computational and athematical Methods in Medicine, Hindawi Publishing Corporation, pp.1-9. 2012.

[10] C. Moreno, and K. Bhaganagar, "Modeling of Stenotic Coronary Artery and Implications of Plaque Morphology on Blood Flow," Modelling and Simulation in Engineering, Hindawi Publishing Corporation, pp.1-14, 2013.

[11] E. E. Guérios, R.R.L. Bueno, P.M.P. Andrade, D. C. Nercolini, Á. L. A. Pacheco, J. C. E. Tarastchuk, and L. F. Kubrusly, "Aneurysm of the Left Main Coronary Artery," Arq Bras Cardiol , vol. 75, pp. 534-536, 2000.

[12] P.S. Douglas, J. Fiolkoski, B. Berko, and N. Reichek, "Echocardiographic visualization of Coronary artery anatomy in the adult", J. Am Coll Cardiol, vol. 11, pp. 565-571,1988.

[13] B.F. Waller, C.M. Orr, J. D. Slack, C. A. Pinkerton, J. van tassel , and T. Peters, "Anatomy, Histology, and Pathology of Coronary Arteries," A Review Relevant to New Interventional and Imaging Techniques-Part I," Clin. Cardiol, vol. 15, pp. 451-457, 1992.

[14] J. P. O.Brien, M. B. Srichai, E. M., D. C. Kim, and J. E. Jacobs, "Anatomy of the Heartcat Multidetector CT: What the Radiologistc Needs to Know," Radio Graphics, vol.27, pp.1569–1582, 2007.

[15] J.D. Bronzino, "The Biomedical Engineering HandBook," Second Edition, and Boca Raton: CRC Press LLC, pp.525-528, 2000.

[16] P. spiller, F.K. Schmiel, B. Politz, M. Block, U. Fermor, W. Hackbarth, J. Jehle, R. Korfer, andf K Pannek, "Measurement of systolic and diastolic flow rates in the coronary artery system by x-ray densitometry, Circulation," vol.68, No. 2, pp. 337-347, 1983.

[17] T. Frauenfelder, E. Boutsianis, T. Schertler, L. Husmann, S. Leschka, D. P. B. Marincek, and H. Alkadhi, "In-vivo flow simulation in coronary arteries based on computed tomography datasets: feasibility and initial results," European Radiology, vol. 17(5),pp.1291-1300, 2007 .

[18] ANSYS FLUENT, Version 15, "Theory Guide," 2014.

[19] T. Shih , W. Liou , A. Shabbir, Z.Yang, and J.Zhu, "A New κ-ε Eddy- Viscosity Model for High Reynolds Number Turbulent Flows – Model Development and Validation," Computers Fluids. 24(3), 227–238, 1995.

[20] T.J. Fogarty, R.A. White, "Peripheral Endovascular Interventions," Springer Science & Business Media, pp. 11-26, 2013.

[21] Ratan, "Handbook of Human Physiology," Jaypee Brothers Publishers, pp. 91-92, 2004.

[22] B.S. Lewis, M. S. Gotsman "Relation between coronary artery size and left ventricular wall mass," British Heart Journal, vol. 35, pp. 1150-1153, I973.

[23] J.T.Dodge , B. G. Brown, E. L. Bolson, and H. T. Dodge, "Lumen Diameter of Normal Human Coronary Arteries Influence of Age, Sex, Anatomic Variation, and Left Ventricular Hypertrophy or Dilation," Circulation, vol .86, pp.232-246, 1992.

[24] R.E. Klabunde, "Cardiovascular Physiology Concepts," Second Edition, Published by Lippincott Williams & Wilkins, pp. 27-28, 2011.

[25] L.E.C.C. Kirkhorn, and J.L. Banasik, "Pathophysiology," Elsevier Health Science,5th Edition, pp.316, 2012.

[26] P.S. Mishra, and Biophysics, "Dynamics of blood flow," FK Publications, pp.133, 2009.

[27] L.J. Greenfield, and M.W. Mulholland, "Essentials of Surgery: Scientific Principles and Practice," Lippincott Williams & Wilkins, pp. 547, 1997.

[28] G. Schmid-Schönbein, and D.N. Granger, "Molecular Basis for Microcirculatory Disorders," Springer Science & Business Media, pp.143. 2013.

[29] A.M. Malek, S.L. Alper, and S. Izumo, "Hemodynamic shear stress and its role in atherosclerosis," (JAMA) The Journal of the American Medical Associatio, vol. 282(21), pp. 2035-2042, 1999.

[30] J. Tu, K. Inthavong, and K.K.L. Wong, "Computational Hemodynamics—Theory, Modeling and Applications," Biological and Medical Physics, Biomedical Engineering, Springer, pp. 95-100, 2015.

[31] R.S. Snell, "Clinical Anatomy by Regions," Lippincott Williams & Wilkins Medical, pp.113, 2008.

[32] L. Deckelbaum ,"Heart Attacks And Coronary Artery disease," Heart Book , Hearst Books , New York, first Edition ,chapter 11 , pp. 133-148, 1992.

Author's biography

N. S. Mahmoud, was born in Iraq 1975, BSc. 1997, Mechanical Engineering from Al-Nahrain University, M.Sc. 2000 in Refrigeration & Air conditioning and Ph.D. 2014 in Thermal Power from the University of Technology, Baghdad-Iraq. Member of Iraqi Engineers Association. He is currently a lecturer at the University of Technology/ Mechanical Eng. Dept. Baghdad-Iraq. His research interests are Heat Transfer, Fluid flow, CFD simulation and Refrigeration & Air conditioning.

A.A. Al-Allaq was born in Iraq-Baghdad in 1985. He received his BS, MSc. degree in medical engineering from the Al-Nahrain University. His project in MSc investigation with lubrication of the human synovial ankle joint. He is currently an assistant lecturer in the ministry of High Education and Scientific Research. His research interests are tribology, biomechanics and biofluid.