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The Computational Fluid Dynamic Simulations for Gangrene Disease in Diabetic Foot

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Abstract

The diabetic foot is considered one of the long term diabetes complications caused by a defect in blood vessel and nerve system. This requires dealing with diabetic foot with professional medical care, so as to prevent its development in advanced stages which could end to gangrene and amputation of the foot. This study has been initiated through follow-up of twelve patients with diabetes and the presence various occlusions in lower limb artery. One patient from them was chosen for investigation, this patient has stenosis in popliteal artery and presence multiple stenosis in superficial femoral artery. This study based on analysis present case of patient and prediction for progress stenosis in superficial femoral artery till arrive semi total occlusion of the artery and interpret the occurrence of gangrene in the lower limb. The geometrical values of the artery and stenosis were acquired measured directly from the patient by using angiography device. The disease of gangrene and artery stenosis in diabetic foot has been investigated by using a simulation program (ANSYS Fluent CFD). The results of study by using four models with (75%, 90%) stenosis from original artery diameter in the healthy patient case are presented and compared with present and healthy case (without stenosis). It has been appeared, with presence of multi stenosis in superficial femoral artery for diabetic foot, and by assuming the blood to be a Newtonian fluid, a significant increase in the blood velocity and wall shear stress in the area of stenosis compared with non stenosis region. The blood flow rate was decreased constrained as the degree of stenosis increased and vice versa. Peak blood velocity is about (0.88) m/sec for healthy artery, it reaches (2) m/sec for a 42.4% stenosis (current case).The maximum velocity values were (10.36, 49.31) m/sec for 75%, 90% stenosis respectively. The maximum wall shear stress at the stenosis region varies from (1094) pa in the 75% stenosis to (15916) pa in the 90% stenosis against a values of (6.36, 380.5) pa in the healthy artery, current case respectively.

Keywords: *Diabetic foot, artery stenosis, gangrene, blood velocity, wall shear stress, mass flow rate, CFD, femoral artery.*

1. Introduction

Diabetes is one of the most prevalent disease in the worldwide, that affects all ages and non-confined on a specific category or a particular age group. Diabetes is a chronic disease, it occurs when the pancreas does not produce insulin in sufficient quantity, or when the body cannot effectively use the insulin it produces. Insulin is the hormone that regulates blood sugar levels. The chronic hyperglycemia (high blood sugar level) of diabetes is associated with long-term complications in the eyes, kidneys, nerves, and blood vessels [1]. Blood vessels are part of the circulatory system, which is concerned in the transfer blood to the body tissue. There are three types of blood vessels: arteries, capillaries and veins. Arteries mission is the delivery of oxygen and nutrients, and the most important glucose, which make the cells and then the tissues that make it up, surviving, so the blood outage or delay arrival at the tissue constitutes a real danger to the tissue or organ, according to the its function. Gangrene is the expression used to depict the death of tissue or necrosis due to failure and blocked blood circulation, usually followed by decay and corruption, a serious potentially lethal complication, which has been well known to generations of physicians for epochs [2]. There are two main kinds of gangrene, wet and dry gangrene. Gas gangrene in some sources assumed as a third type of gangrene in some classify as the type of wet gangrene. Gangrene may influence superficial or deep tissues. Superficial gangrene frequently impacts distal parts of the body such as fingers and toes [3]. Gangrene ordinarily appears the same in both the person with diabetes and the person without diabetes a like [1]. The diabetic patient foots has the possibility endanger of pathologic effect , such as infection , demolition of deep tissues parallel with abnormalities of neurologic ,ulceration, different levels of peripheral vascular disease with metabolic complexity of diabetes in the lower limb [2].Diabetic persons have a 15 times higher risk of lower extremity amputations than non diabetic individuals [4]. Amputation is the final outcome of a cascade of diabetic foot lesions [2].Abnormalities function of endothelial cell lining the artery wall can expose the arterial system to atherosclerosis and its related reverse effects [5]. Atherosclerosis is progressive growth of atherosclerotic plaques in the artery. In progress stage of atherosclerosis, plaques will become stenotic and cause progressive obstruction of the arterial lumen [6], as shown figure (1). Many factors have been involved in atherosclerosis pathogenesis, include hypertension, cigarette smoking, diabetes, hyperlipidemia, and hyperhomocysteinemia [7]. The peril of the foot amputations or ulcers is raised in patients who have diabetes greater than or equal to 10 years, have poor regulation of blood sugar, or have cardiovascular disease [8]. The most common pathway linked with the development of diabetic ulcers involves peripheral neuropathy; approximately 30% of diabetics have moderate to significant forms of nerve harm. Absence sensation leads to unfeeling foot more vulnerable to pressure points and repetitive activity [9,10].

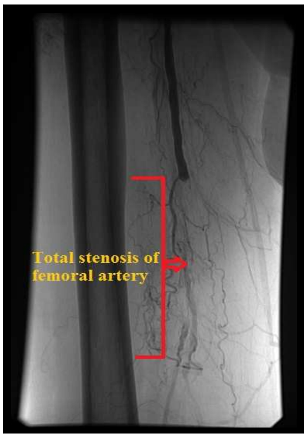


Fig. 1. Show total femoral artery occlusion for man has (65) years old with diabetes history, the patient diagnosed in Al-Shaheed Gazi hospital/ department of radiology at 2016.

The diabetes is widespread widely in the world and has a direct impact on human health and the sustainability of his life , so there are a lot of medical researchers that interested about diabetic and focused to pathological cases associated with this disease, such as diabetic foot and gangrene.

Suguru et al 2001 [11] presented report about follow-up 27 patients with diabetic foot, average age 67 years. All patients in this study suffer type (2) of diabetes, diabetic neuropathy, and more than 60% of these patients have arteriosclerosis disease. The follow-up period was (2 years and 3 month), amputated 35 of lower limbs from 27 patients , Thirteen patients died during 1 day to 1187 days after the amputate operation.

Edward et al 2001 [12] presented study the relationship between diabetes and peripheral arterial disease. This investigation has showed that diabetic patients suffered peripheral arterial disease in the lower limb region with risk of amputation and probability died at a younger age than nondiabetic patients. The other point of study conclusion showed the worse disease in diabetic patients happen in the femoris artery.

Paulo et al 2005 [13] presented a case of ulceration and leg ischemia caused by progressive stenosis in the right common femoral artery. This study assumed that frequent arterial damage caused the effect of diabetes result the cumulative common femoral artery stenosis.

All the above researches confirms the relationship between diabetes and lesions of arteries in the important parts of the human body as a result of this disease ,an example that the arteries of the foot .In some cases diabetic disease leads to the amputation of a damage part cause lack or reduced access of blood nutrition to this part . Atherosclerosis are early development in the diabetic patients and more dangerous than non-diabetics. Artery disease is a dangerous, whether the artery stenosis or aneurysm. Its direct impact on human health , so this disease has led to the attention of a lot of the researchers to work engineering analysis of the disease by simulating what happens inside the defect artery and investigation about all parameter that change from normal case.

Mingxiu 2006 [14] investigated the biomechanical forces and vessel wall motion with the advancement of stenosis acuity under realistic loading conditions by using coupling of the computational fluid dynamics packages FLUENT and the finite element modelling packages ABAQUS and software program (MATLAB) script. The results showed extreme wall shear stress is about 6 Pa for healthy arteries, it reaches 45 Pa for a 30% stenosis (by diameter),and for more than or equal to 50% stenosis. Wall motion was increasingly constrained as the degree of stenosis increased.

Luisa et al 2011 [15] studied the blood velocity and wall shear stress of the artery stenosis 3D model, use computational finite element and Navier-stokes equations to perform this investigation. Simulated outcomes are evaluated and compared with literature data acquired from ultrasound device measurements.

Sónia et al 2012 [16] reported a preliminary numerical study of blood flow in a bifurcation channel with stenosis. The package program (ANSYS) was used to execute the numerical study. The blood flow in a channel provided with a moderate stenosis (65% of obstruction) was compared with that in a severe stenosis (90% of obstruction). For a severe stenosis, the static pressure drop was higher, the difference between mass flow rates in both branches of the bifurcation is also higher, and small recirculation parts were observe following the stenosis region. Padukkage et al 2014 [17] studied a comparison between an axisymmetric stenosis model in the common femoral artery and an eccentric model in terms of wall shear stress distribution and oscillatory shear index. Blood was assumed in this study a Newtonian fluid. This study concludes that when implement computational fluid dynamics simulation to determine the regions that are more susceptible to subsequent stenosis. It was unwise to assume complete symmetry of the blood obstruction in the artery. Nabeel et al 2017[18] presented numerical study the effects of aneurysm and stenosis in left coronary artery on the blood velocity, mass flow rate of blood and wall shear stress of artery by using simulation program (ANSYS Fluent) .This investigation reached several conclusions, including that insufficiency blood supply by the coronary arteries to the heart muscle with stenosis presence leads to ischemia and myocardial infarction.

The stenosis of the arteries was impact on the blood velocity, wall shear stress of artery and lack that occurs in the desired amount of blood delivered to the body organ. From relationship between diabetes disease and gangrene the idea of this research was emerged. The present study investigates the Influence of artery stenosis in diabetic foot on the occurrence of gangrene.

2. Materials and Methods

2.1. Patient Data Selection

Twelve patients with diabetes and peripheral artery disease were follow-up in the department of radiology for evaluation of arterial disease in the lower extremities. The imaging techniques computed tomography and x-ray angiography were used for diagnosis cases study. Angiography is a diagnostic, therapeutic form concerned with circulation system diseases. In this technique, the vessels of concern are opacified by injection of a radiopaque contrast agent. Contrast substance is required to opacify vessel structures because the radiographic contrast of blood is essentially the same as that of soft tissue [19].These 12 patients, 4 woman and 8 men, had a mean age of 62 years and a mean duration of diabetes of 10 years. The follow-up duration was 15 month. The characteristics of the patients are presented in Table (1)

Table 1,
Details of patients information.

Patient No.	Age	Sex	Location of Stenosis	Percentage of stenosis	Notes for patient case	Site of diagnosis	diagnosis device
1	69	female	right femoral artery right popliteal artery	38% - 42% multi stenosis 90%	multi stenosis along femoral artery , progress to total occlusion in popliteal artery	Al-Shaheed Gazi hospital / department of radiology	Angiography/ Siemens Axiom Artis
2	80	female	right femoral artery	67%-100%	amputated two toes from right foot by cause gangrene		
3	36	male	Right common iliac artery	75%	-		
4	58	male	Right popliteal artery	95%	slight stenosis in right femoral artery		
5	71	male	Left femoral artery	99%	distal femoral artery takes blood from collateral artery		
6	70	male	right femoral artery	50%	-		
7	65	male	right femoral artery	100%	additionally ,stenosis occurs in collateral artery		
8	73	male	right common iliac artery	57%	amputated the left leg		
9	65	female	left femoral artery	65%	additionally, the presence acute stenosis in the coronary artery		
10	50	male	right aorta + common iliac artery	100%	amputated the left leg caused by total stenosis in left femoral artery		
11	52	male	right common iliac artery	100%	chronic stenosis in common iliac artery ,femoral artery takes blood from collateral artery	Ibn Alnafees hospital / department of radiology	Computed Tomography/ Toshiba Aquilion
12	57	female	right femoral artery	100%	femoral artery bypass surgery was performed to treatment the total stenosis in artery, and then stenosis occurs in bypass itself.		

This investigation was performed on the patient no. (1) shown in the above table. This patient was female, has age (69) years, heavy smoker, diabetes existent about ten year ago. She was suffering from pain and claudication in the right lower limb, when the diagnosis by angiography device showed a stenosis occurs in the femoral and popliteal artery. This patient has been chosen be investigated for many reasons, the artery stenosis existence more than one region, in femoral artery and popliteal artery and presence multiple stenosis in femoral artery, as shown in Figure (2).

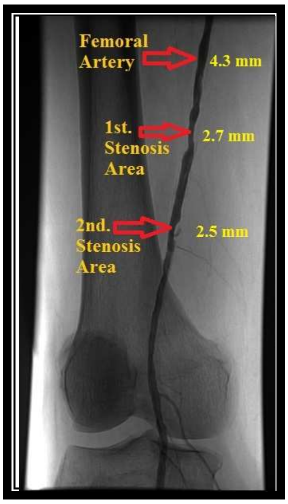


Fig. 2. Show multiple stenosis in femoral artery for female patient has (69) years old, heavy smoker, with diabetes history, the patient diagnosed in Al-Shaheed Gazi hospital/ department of radiology at 2016.

2.2. Computational Model

Anatomically, the common femoral artery bifurcation in two branches the superficial femoral artery and profunda femoris. The superficial femoral artery is a direct extension and locates the same axis of the common femoral artery [20]. The superficial femoral artery is the most common site of multiple stenotic lesions, so the profunda femoris tends to be spared [21].The superficial femoral artery was studied in this search, shown in figure (2).All real dimensions, length, diameter and percentage stenosis of artery taken directly from angiography device when the patient number (1) in the table (1) under diagnosis. The length of the selected part of artery for this study was (14) cm and diameter (4.34) mm. The stenosis diameters were (2.7, 2.5) mm with length (1) cm in stenosis area (1) and area (2) respectively, as shown in figure (2). This study based on the simulated the present patient case and future prediction of the artery stenosis progress until access the semi total occlusion of artery and compare with healthy case (without stenosis), progress of stenosis assumed two stages,stenosis (75%,90%)from orginal diameters with (1.085, 0.434) mm respectively ,as shown in Figure (3).

2.3. Physiological Parameters

The behavior of the blood in the human femoral artery has been assumed Newtonian fluid. It is assumed that when the diameter of the artery is large compared to the size of suspension particles, blood can be treated as Newtonian and viscosity can be considered as constant [14].Non-newtonian effects are only considered in small vessels with an internal radius less than (0.5) mm [14,22]. So the assumption of Newtonian flow in this study can be considered valid. Suitable rheological parameters for human body were applied with a blood density of (1060) kg/m^3 and constant blood viscosity of (0.0035) Pa s [23]. The measurement of blood velocity in human arteries has possibility use both in physiologic studies and in the estimation of patients for arterial disease, the blood velocity information can be obtained by ultrasonic techniques. The blood velocity was applied as an inlet boundary condition in superficial femoral artery, the peak systolic average velocity was taken as range (60) cm/sec as mention in [24].

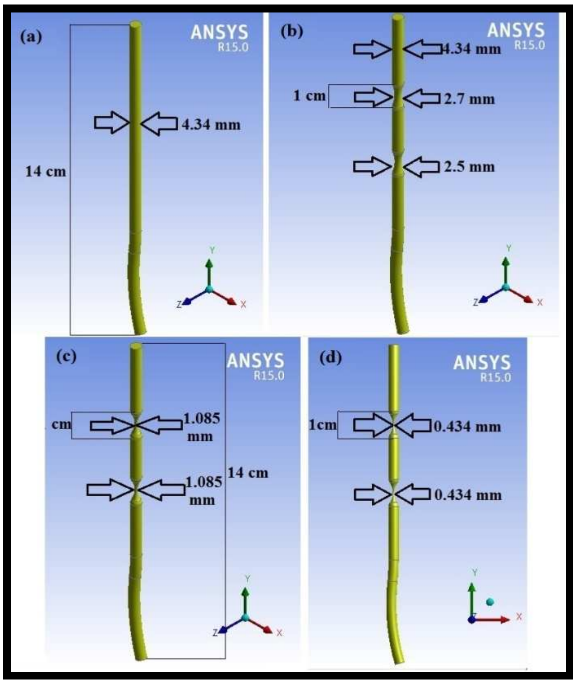


Fig. 3. Show design selective length of right superficial femoral artery (a) healthy case (b) current case (c) 75% stenosis (d) 90% stenosis (semi total occlusion).

2.4. The Computational Method of Hemodynamic Analysis

A finite-volume method package (ANSYS Fluent code version (15.0) was used to solve the equations of Navier-Stokes, continuity equation, momentum conservation [25] on a Microsoft windows (7) 64-bit machine, 4GB RAM with an Intel core I3 CPU.

A mesh independence test was carried out depending on the mass flow and velocity of blood using three grid sizes (500,000-750,000 and900,000) of tetrahedral elements, this leads to the selection of mesh size of (900,000) concentrated near to predict boundary layer of velocity gradient . A Finite-volume based technique that consists of the following steps is used for solution :- (a) A grid is generated on the domain, which was previously explained. (b) For velocity, pressure, and conserved scalars, algebraic sets of equations are constructed by the integration of the governing equations on each control volume. (c) Discretized equations are linearized and solved iteratively.

3. Results and Discussion

The performed this investigation reflected the effect of stenosis on the blood flow characteristics. This impact is very significant and complex to study in vivo, for this purpose emanate the numerical study. All changes that occur on the blood velocity, blood flow rate and wall shear stress in the superficial femoral artery due to the impact of diabetes and incidence artery stenosis to reach stage of gangrene in human foot were investigated and calculated by use ANSYS (CFD) simulations program. The variations of blood velocity is one of the important factors for indication of artery stenosis, for this reason the velocity studied on five different axial locations along the length of the artery to understand and precision description of events inside the artery under various pathological conditions of the superficial femoral artery and compartment with healthy case (without stenosis). The axial location sections are chosen related to the presence stenosis lesions area in this position and compare them with same location in the healthy artery. The sections (s1.s3) are located before (1) cm from first and second stenosis area, (s2, s4) are located at middle of stenosis region. Also the sections (s3, s5) are located after (1) cm from first and second stenosis area respectively, as shown in figure [4].

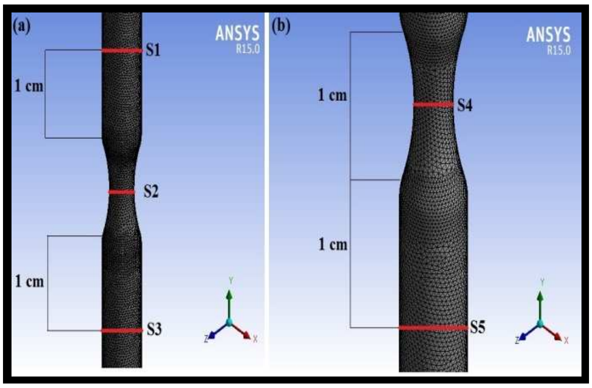


Fig. 4. The section lines at (a) first stenosis area , (b) second stenosis area .

The velocity of blood is the rate of displacement of blood per unit time. The blood vessels of the cardio vascular system vary in terms of diameter and cross section area. These variations in diameter and area in turn, have deep effects on velocity of blood as eq. (1) [26].The other factors that impact the blood velocity profile include the entrance effect, skewing, vessel curvature, turbulence, stenosis, acceleration, and secondary flows [19]. The equation (1) shows the inverse relationship between diameter of artery (or diameter of stenosis) with velocity, this explain the increase of blood velocity in the stenosis region.

$$V = \frac{Q}{A} \leftrightarrow \frac{cm^3/\sec}{cm^2} = \frac{cm}{\sec} \quad \dots (1)$$

The blood velocity can be seen in figures (5, 6, 7, 8, 9 and 10) increasing in the center region of blood flows in vessels due to the effect of intima friction with cellular component of the blood, intima refer the inner layer of blood vessel wall. Poiseuilles law as mention in eq. (2), states that resistance to blood flow in a blood vessel proportionately varies directly with length of vessel and viscosity of blood and inversely with fourth power of radius of lumen of vessel [27].

$$R = \frac{8L\eta}{\pi r^4} \quad \dots (2)$$

The peripheral resistance define, is the frictional resistance offered by the circulatory system to the flow of blood. Blood flows in vessels in a series of concentric layers with ever increasing velocity in the center. The various layers moving at different velocities cause frictional resistance to the flow [27].

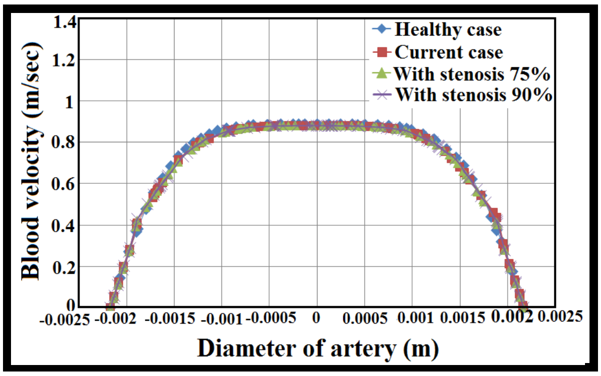


Fig. 5. Variation of velocity at section (S1) in superficial femoral artery for multi case of stenosis and compare with healthy case.

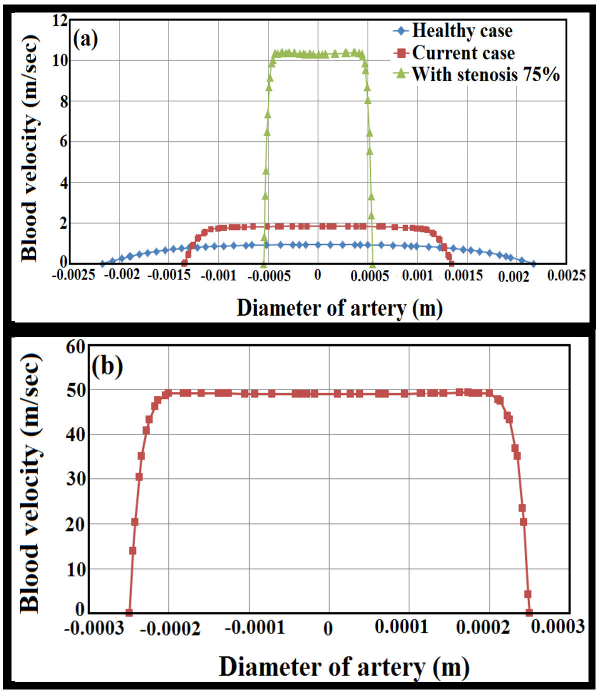


Fig. 6. Variation of velocity at section (S2) in superficial femoral artery with (a) 75 % of stenosis compare with current and healthy cases, (b) with 90 % of stenosis.

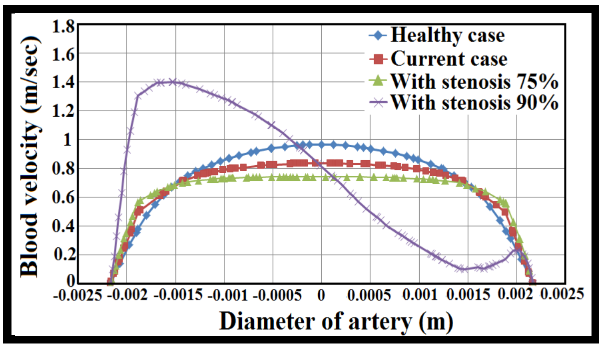


Fig. 7. Variation of velocity at section (S3) in superficial femoral artery for multi case of stenosis and compare with healthy case.

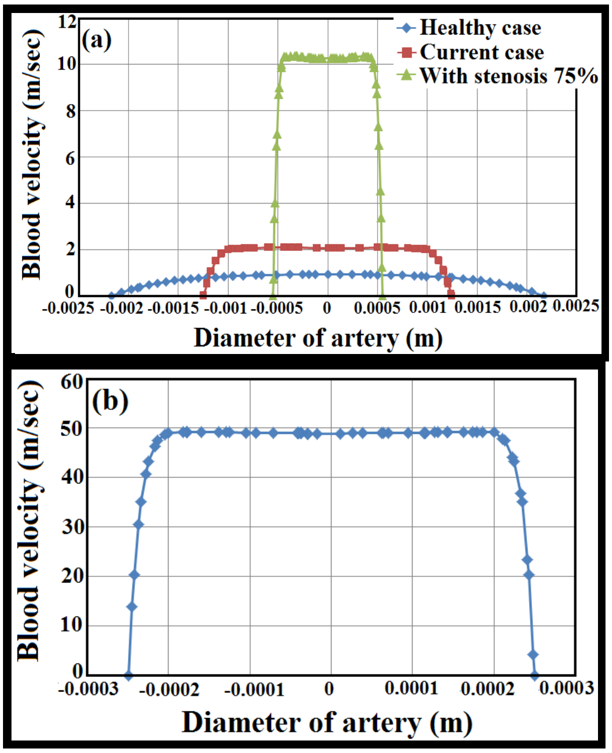


Fig. 8. Variation of velocity at section (S4) in superficial femoral artery with (a) 75 % of stenosis compare with current and healthy cases, (b) with 90 % of stenosis.

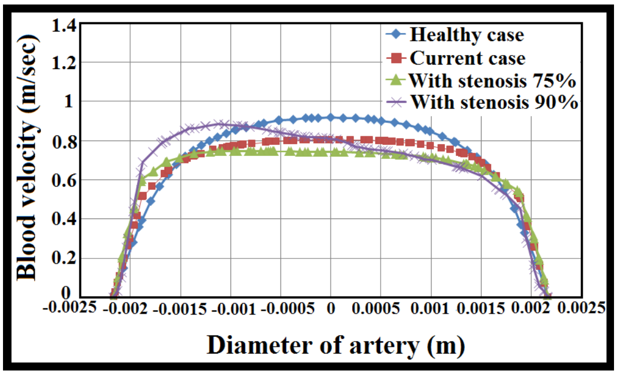
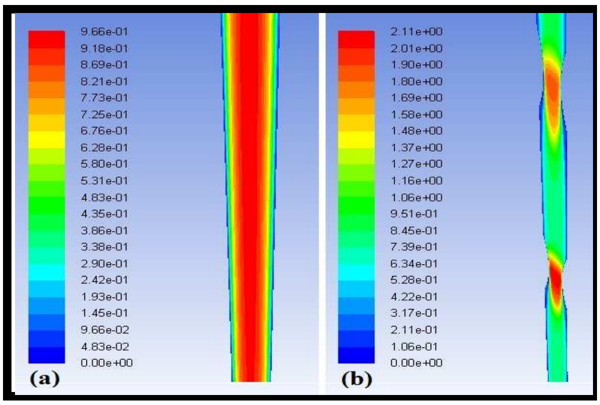


Fig. 9. Variation of velocity at section (S5) in superficial femoral artery for multi cases of stenosis and compare with healthy case.



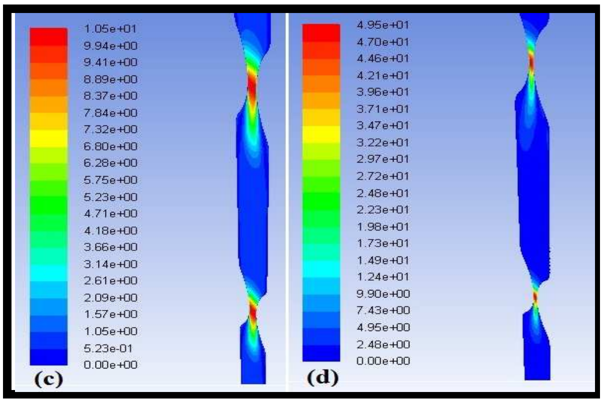


Fig. 10. Variation of contours velocity (m/sec) at (a) healthy case, (b) current case, (c) 75 % of stenosis (d) 90 % of stenosis.

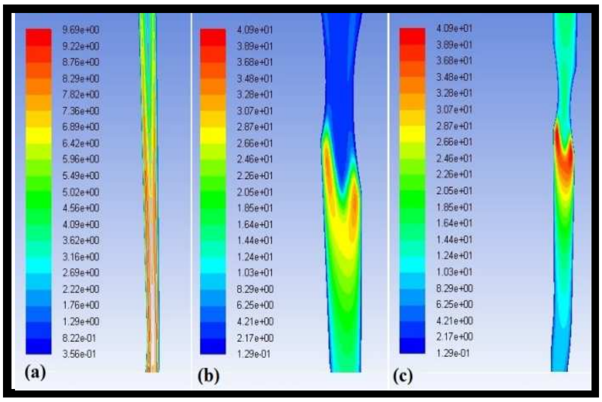


Fig. 11. Turbulent intensity countours (%) in superficial femoral artery (a) healthy case, (b) first stenosis area at current case, (c) second stenosis area at current case.

The change in diameter of the artery like stenosis leads to several differences in the natural appearance of the blood flow. Laminar flow is the normal case throughout most of the circulatory system and is described by concentric layers of blood moveable in parallel along of a blood vessel. Turbulent flow is a flow case characterized by anarchic and rapid changes in pressure and flow velocity. Turbulence occurs when smoothly flowing, laminar flow is disrupted, distal to stenotic [28]. As the stenosis becomes high stage, turbulence is likely to occur downstream of the stenosis. The turbulent intensity is also larger in a tighter stenosis [29]. Turbulence in blood flow increases the energy desired to propel blood flow because it increases the loss of energy in the form of friction with artery wall, which produce heat [30]. In areas of turbulence, platelets and endothelial cells may be activated, leading to thrombosis in artery [31].In stenosis area can be seen, an increase in blood velocity and change the normal form of blood path in addition , the energy dissipated or lost in this region as a result of the turbulent flow .So we can imagine the extra load that falls on the heart as a result of this multi stenosis also the disruption in the amount of blood that expected access in the post-stenosis stage whether an artery or effective organ, shown in figures (11) and (12).

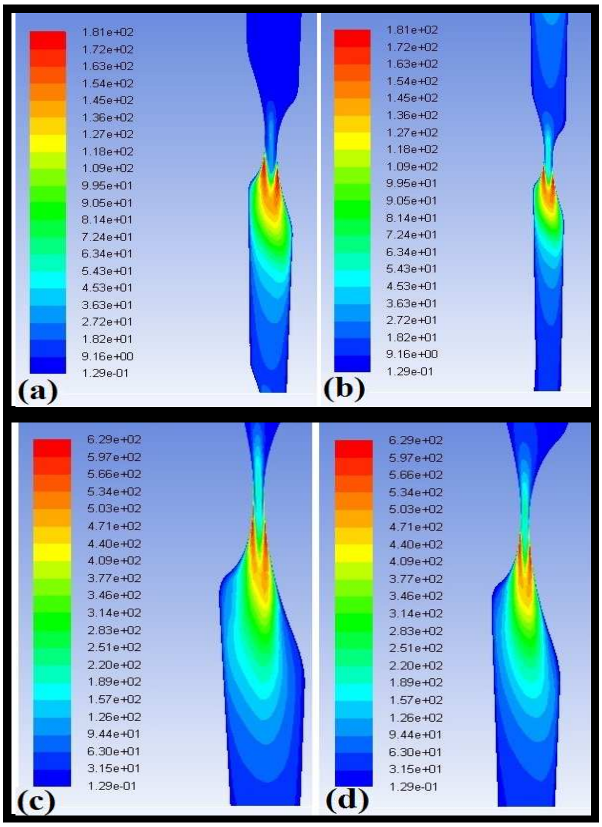


Fig. 12. Turbulent intensity countours (%) in superficial femoral artery (a) first stenosis area at 75% of stenosis ,(b) second stenosis area at 75% of stenosis , (c) first stenosis area at 90% of stenosis , (d) second stenosis area at 90% of stenosis.

The impact of stenosis in arteries of diabetic foot on the wall shear stress (wss) distribution and magnitude for various cases was studied. The vascular system cells are permanently exposed to mechanical forces (hemodynamic) due to the blood flow. The forces produced in the vessels comprise the fluid shear stress or frictional force act on the blood flowing tangentially across the endothelium, a pure normal stress caused by a hydrodynamic pressure differential across the vasculature wall , and a tensile stress caused by circumferential vasculature wall deformations [19]. In this research, (wss) was computed along the inner wall of the superficial femoral artery at two longitudinal lines (wss1, wss2) located on the first and second stenosis area respectively, as shown in figure (13). The purpose of longitudinal lines locations was selected synchronize to the presence stenosis in this area and compare it with the same location with healthy artery. The executed results show the variation of (wss) for the selected stenosis cases at the chosen locations on the artery as shown in figures (14), (15) .The value of (wss) depends on the magnitude of this velocity gradient at the vessel wall. That (wss) is measured adjacent to the vessel wall and for the cylindrical tube is calculated as [32].

$$wss = \frac{8\eta V}{d} \qquad \ldots (3)$$

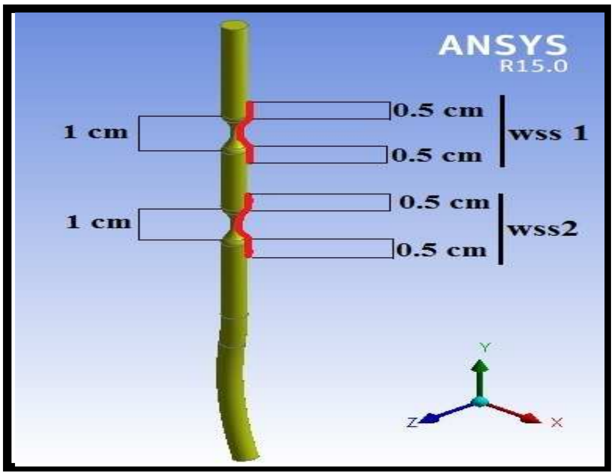
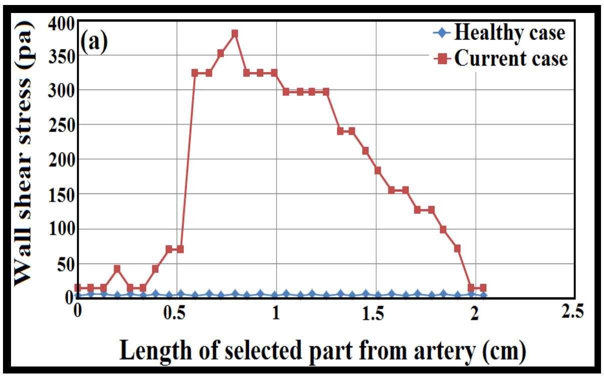


Fig. 13. Selected locations of wall shear stress in superficial femoral artery.



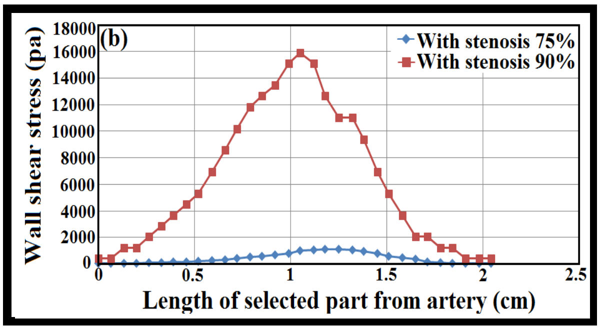


Fig. 14. Variations of wall shear stress along the first longitudinal section (wss1) of superficial femoral artery (a) for healthy and current cases (b) with 75 % and (90) % of stenosis.

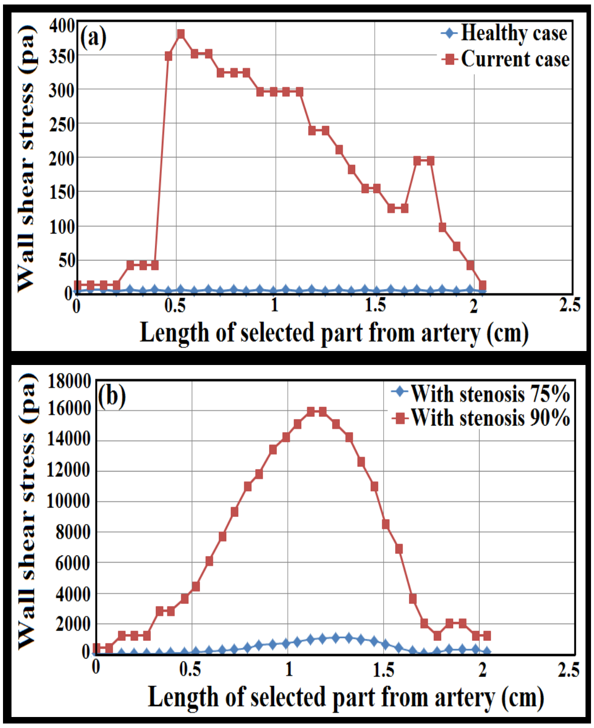


Fig. 15. Variations of wall shear stress along the second longitudinal section (wss2) of superficial femoral artery (a) for healthy and current cases (b) with 75 % and (90) % stenosis.

From equation (3), the value of (wss) is directly proportional with blood velocity and blood viscosity and inversely proportional to the diameter of vessel. Thus the stenosis of artery or reduce in vessel diameter will have a large impact on the (wss) as seen in figures (14), (15).Thus a slight change in vessel diameter will have a big impact on (wss) .Shear stress has an instant impact on the endothelial cell, which reply to rise in shear stress by secretion nitric oxide, leads to vasodilatation and relaxation smooth muscle cells of artery wall [33]. The effects of high wall shear stress orientation of endothelial cells and the subsequent production and release of factors that prevent coagulation, allow migration of white blood cells, and induce smooth muscle proliferation, while simultaneously encourage endothelial cell survival [7]. For this reasons, the physician is given advice to patient or healthy person, to work daily sport or continuous movement if possible because this effectiveness lead to increased blood velocity and increase (wss), then increase flexible of artery and vasodilatation occurs. Vasodilatation is dilation of blood vessels led to raise of blood nourishment to tissues that necessity it most.

Gangrene is disease caused lack or obstruction of the blood supply to organ. It is necessary to know and measure the amount of blood that arrive in the event of an artery stenosis in diabetic foot and compare it with the healthy case (without stenosis) as shown in figure (16).Mass flow rate of blood is defined as the mass of blood passes per unit time. Mass flow rate is dependent on many factors such as blood velocity, area of flow, and blood density, as eq. (4) [23].

$$m=\rho*V*A \quad \ldots (4)$$

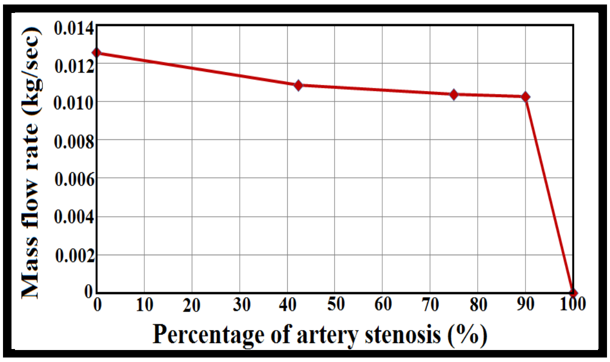


Fig. 16. Variation of the mass flow rate of blood in superficial femoral artery at second stenosis area for five percentage of stenosis, 0% stenosis (healthy case), 42.4 % stenosis (current case), 75% stenosis, 90% stenosis and 100% stenosis (total stenosis).

The mass flow rate in figure (16) have been calculated by apply blood density, area of stenosis and blood velocity in each stenosis cases in eq. (4), the values of blood velocity were taken from output result data of execute simulation in section (s4) for each selected case, when total stenosis (area of flow equal zero) causing the value of the mass flow rate in artery shift to zero. The blood arrives to superficial femoral artery from aorta by common iliac artery. The superficial femoral and popliteal arteries are the most vessels usually influenced by the atherosclerosis. Atherosclerosis influence the lower limbs is the general form of peripheral vascular disease. It leads to clinical cases extending from intermittent claudication or pain at rest to non-healing ulcers and gangrene [34] .Most cardiovascular risk factors for patient with peripheral arterial disease are comparable for patients with diabetes alone. General agreement strongly supports that both peripheral arterial disease and diabetes are related with considerably increased risks of cardiovascular disease [5]. The superficial femoral artery is undergoing to different forces, such as flexion, compression, extension, contraction, and torsion, which have caused many therapies to failure. The health of superficial femoral artery has also been important for saving patients' quality of life and limbs. Various ways exist for therapies the superficial femoral artery, angioplasty balloons, covered stent grafts, plaque atherectomy instruments (endovascular surgery technique for removing atherosclerosis from blood vessels), and a numerous of chronic total stenosis instruments all supply endovascular doctors with wide options according to patients case. [35].

4. Conclusions

1. In the stenosis region occurs turbulence blood flow. The blood velocity in this region will become so fast and inverse proportion relationship with diameter of stenosis, and vice versa.
2. Increase blood velocity in stenosis region accompanied with increment wall shear stress. Vasodilatation has direct affect by increase wall shear stress cause impact on the internal tissue of artery lumen.
3. Blood flow rate is suffered irregular and disorder by cause of multi stenosis in superficial femoral artery, this leads to lack arrive blood and insufficiency nourishment that needed to sustain life of foot tissue.
4. Stenosis of artery and reduce necessary blood that arrive to organ by this artery leads to gangrene of the affected organ because the death of living cells as a result of non-arrival of the necessary nutrition.

Notation

Symbol	Meaning	unit
V	Blood velocity	m/sec
P	Pressure	pa
ρ	Density	kg/m^3

Q	Blood flow	ml/sec
A	Cross section area of artery	cm^2
R	Resistance	pa sec/cm^3
L	Length of vessel	cm
η	Viscosity of blood	pa sec
r	Radius of blood vessel	cm
d	Diameter of vessel	cm
wss	Wall shear stress	Pa
m	Mass flow rate	kg/sec

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محاكاة ديناميكية الموائع الحسابية لمرض الغرغرينا في القدم السكرية

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الخلاصة

تُعدُ القدم السكري واحدة من مضاعفات مرض السكري على المدى الطويل سببها خلل في الأوعية الدموية والجهاز العصبي. وهذا يتطلب التعامل مع القدم السكري برعاية طبية محترفة، وذلك لمنع تطورها في المراحل المتقدمة يمكن أن ينتهي إلى الغرغرينا وبتر القدم. وقد بدأت هذه الدراسة من خلال متابعة اثني عشر مريض لديهم مرض السكري ووجود انسدادت مختلفة في شريان أطرافهم السفلى.وقد تم اختيار مريض واحد منهم للتحقيق، هذا المريض لديه تضيق في شريان باطن الركبة وجود تضيق متعدد في الشريان الفخذي السطحي.ارتكزت هذه الدراسة على تحليل الحالة الراهنة للمريض والتكهن بتقدم الانسداد الذي يحدث في الشريان الفخذي السطحي حتى يصل الانسداد شبه الكلي للشريان وتفسير حدوث الغرغرينا في الطرف السفلي.تم الحصول على قياس القيم الهندسي للشرايين والتضيق مباشرة من المريض باستخدام جهاز تصوير الأوعية. وقد تم التحقيق من مرض الغرغرينا و تضيق الشرايين في القدم السكري باستخدام برنامج محاكاة (ANSYS Fluent CFD). وتعرض نتائج الدراسة باستخدام أربعة نماذج مع (٧٥٪، ٩٠٪) تضيق من قطر الشريان الأصلي في حالة المريض الصحية ومقارنتها مع الحالة الراهنة والصحية (بدون تضيق). وقد ظهر ذلك، مع وجود تضيق متعدد في الشريان الفخذي السطحي للقدم السكري، وبافتراض الدم انه سائل نيوتوني، زيادة كبيرة في سرعة الدم و إجهاد جدار القص في منطقة التضيق مقارنة مع المنطقة الخالية من التضيق. وقد انخفض معدل تدفق الدم مقيدة بدرجة زيادة التضيق والعكس بالعكس. بلغت ذروة السرعة حوالي (٠,٨٨) م / ثانية في الشريان الصحي، وبلغت (٢) م / ثانية لتضيق ٤٢,٤٪ (الحالة الحالية). وكانت قيم السرعة القصوى (١٠,٣٦، ٤٩,٣١) م / ثانية لنسب التضيق ٧٥٪ ، ٩٠٪ على التوالي. يتراوح إجهاد جدار القص الأقصى في منطقة التضيق من (١٠٩٤) باسكال في تضيق ٧٥٪ إلى (١٥٩١٦) باسكال في تضيق ٩٠٪ مقابل قيم (٦,٣٦، ٣٨٠,٥) باسكال في الشريان الصحية، الحالة الراهنة على التوالي.