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The Effect of Doppler Phenomenon on the Speed of Blood Flow

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Abstract

This research studying the phenomenon of Doppler (frequency Doppler) as a method through which the direction and speed of the blood cells flows in blood vessels wear measured. This Doppler frequency is relied upon in medicine for measuring the speed of blood flow, because the blood flow is an important concept from the concepts of medicine. It represents the function and efficient of the heart and blood vessels in the body so any defect in this function will appear as a change in the speed of blood flow from the normal value assumed. As this speed changes alot in cases of disease and morbidity of the heart, so in order to identify the effect of changing the Doppler frequency on the speed of blood flow and the relationship of this frequency with the angles of transitions and receptions and the effect of changing the ultrasound transmitted frequencies on the measured velocities .The Doppler ultrasound system has been used which is more efficient and easier to be widely used as a practical application in Al Yarmouk Teaching Hospital on two subjects. The normal had a natural medical history in the blood vessels, and abnormal had carotid artery stenosis. This device will give the flow velocity of blood in the blood vessels which is useful to the examiner, the equation of Doppler as a mathematical model in the research is adopted the measured speed to clarify the amount of change in the frequency (shift in frequency). This speed was measured in five different blood vessels, large arteries (abdominal aorta and carotid artery in the neck) and large veins (the inferior vena cava across the abdomen and the external Jugular vein in the neck) and capillaries in the hand and fingers. Then using the measured velocities in these vessels the Doppler frequency was calculated from this mathematical model using MATLAB program, was found that as velocity of the blood increases, so does the Doppler frequency and vice versa. The greater the value of the Doppler angle used in the device then the Doppler frequency decreased and vice versa. As well as increasing the transmitted frequency giving an increase in the speed of blood flow and in the Doppler frequency and vice versa. It was observed during the practical work that it was possible to get the speed of blood flow in different blood vessels, arteries and veins easily, but to less extent in the capillary vessels since in fact the value of the received frequency was very small.

Keywords: *Doppler frequency, blood flow, ultrasonic blood flow meter.*

1. Introduction

The Doppler Effect provides a unique capability for ultrasound to measure blood flow [1]. The Doppler principle states that the frequency of reflected ultrasound is altered by a moving target, such as red blood cells. The magnitude of this Doppler shift relates to the velocity of the blood cells, whereas the polarity of the shift reflects the direction of blood flow toward (positive) or away (negative) from the transducer [2]. The Doppler frequency shift is a change or shift in the frequency of the returning echoes compared to the frequency of the transmitted ultrasound waves which the basis for calculating blood flow velocities ,negative frequency shift (echoes reflected from blood flowing away from the transducer have lower frequencies compared to the transmitted ultrasound), positive frequency shift (echoes reflected from blood flowing toward the transducer have higher frequencies compared to the transmitted ultrasound) ,net frequency shift (echoes reflected from blood flowing perpendicular to the transducer exhibit no change in frequency compared to the transmitted ultrasound) as shown in Fig. (1) [3]. Blood flow through the heart and great vessels has certain characteristics that can be measured using Doppler instruments designed for Medical use.

For the purpose of understanding flow patterns in the heart, it is important to recognize the difference between laminar flow and turbulent (or disturbed) flow [4].Laminar flow is the flow velocity in a straight vessel with uniform diameter; it represents the majority of normal blood flow. Turbulent flow within an arterial or venous system, multiple factors exist that are capable of altering or disrupting laminar flow, as vessel tapering, curvature, bifurcations, and many other abnormal deformations as arterial stenosis and thrombus, cause turbulent flow [5]. The fact that makes the frequency of the Doppler Effect more than just an interesting curiosity is that it actually provides a method that is used to measure the direction and speed of moving red blood cells. Doppler methods extend the use of cardiac ultrasound into the evaluation of normal and abnormal flow states and provide quantitative data that are essential in the clinical decision making process concerning patients with heart disease [4]. Carotid artery disease is also called carotid artery stenosis. The term refers to the narrowing of the carotid arteries. This narrowing is usually caused by the buildup of fatty substances and cholesterol deposits, called plaque. Carotid artery occlusion refers to complete blockage of the artery. When the carotid arteries are obstructed, there will be an increased risk for a stroke [6].

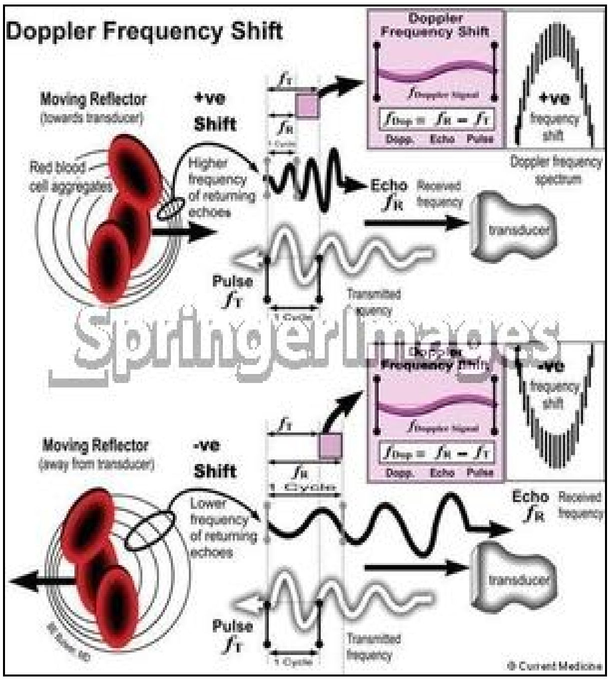

Fig. 1. Doppler Frequency Shift [3].

2. Mathematical Model of Doppler Frequency

The shift in frequency is related to the contraction or expansion of wavelengths ahead of or behind the sound-emitting moving object shown in Fig. (2). the wavelength of the sound, is the speed of sound propagation, *c*, divided by the frequency of the sound. As sound speed is defined in units of length divided by time and frequency is the number of cycles per unit time, wavelength is expressed in units of length. The velocity of the moving object, v, is also in units of length divided by time. As the sound is emitted from the moving object, the wavelengths observed at points on either side of the object are lengthened (l) or shortened (s). Because wavelength is inversely proportional to frequency, the observer will detect a frequency different from that emitted by the object when it has zero velocity [7]:

$$\lambda_l = \frac{c+v}{f} = \frac{c}{f-\Delta f} \qquad \ldots(1)$$

$$\lambda_s = \frac{c-v}{f} = \frac{c}{f+\Delta f} \qquad \ldots(2)$$

In Equations (1) and (2), f is the frequency of the sound emitted by the object and would be detected by the observer if the object were at rest, $(\pm\Delta f)$ represents a Doppler effect–induced frequency shift. The sign depends on the direction in which the object is traveling with respect to the observer. In the case of ultrasound scattering back from moving objects (e.g., red blood cells) in the body, the derivation of the Doppler equation may follow that of Wells Because ultrasound is used in a transmit-echo approach. There is a Doppler effect with the sound arriving at the scattering object and a Doppler effect as the sound is reflected from that object back toward the ultrasound transducer. In US, the round trip time for sound is related to the depth and the speed of sound in tissue. As seen in Equations (1) and (2), an inverse relationship exists between frequency and the wavelength of the sound transmitted to the red blood cells. The sound speed is constant (c tissue = 1,540 m/sec) in this relationship. The frequency of the sound incident on the red blood cell is changed because the relative velocity of the red blood cell is added to the sound propagation speed. The variables can be rearranged in the form of the transmitted frequency, f_0, and an object velocity term [7]:

$$f_0 = \frac{c}{\lambda_0} \rightarrow \lambda_0 = \frac{c}{f_0}\,) \qquad \ldots(3)$$

$$f_{RBC} = \frac{C + V_{RBC}}{\lambda_0} = f_0 + \frac{V_{RBC}}{\lambda_0} \qquad \ldots(4)$$

The sound is then reflected back toward the transducer in the echo from the red blood cell. The frequency of sound arriving back at the transducer is shifted again in proportion to the red blood cell velocity [7]:

$$f' = f_{RBC} + \frac{V_{RBC}}{\lambda_{RBC}} \qquad \ldots(5)$$

$$= f_0 + \frac{V_{RBC}}{\lambda_0} + \frac{V_{RBC}}{\lambda_{RBC}}$$

The equation for the frequency returning back to the transducer, f' can be rewritten once again with respect to the original frequency, f_o, and the wavelengths of the incoming and outgoing waves. These relationships are now substituted into the following equation to put everything in terms of the red blood cell velocity, v_{RBC}, the original frequency, f_o, and the speed of sound propagation, c [7]:

$$f' = f_0 + \frac{V_{RBC}}{\lambda_0} + \frac{V_{RBC}}{\lambda_{RBC}}$$

$$= f_0 + \frac{V_{RBC}}{c}\left(f_0 + f_{RBC}\right)$$

$$= f_0 + \frac{V_{RBC}}{c}\left(2.f_0 + V_{RBC}.\frac{f_0}{c}\right)$$

$$= f_0 + 2f_0\left(\frac{V_{RBC}}{c}\right) + f_0\left(\frac{V_{RBC}}{c}\right)^2 \qquad \ldots(6)$$

$$fD = f' - f_0$$

$$= f_0 + 2f_0\left(\frac{V_{RBC}}{c}\right) + f_0\left(\frac{V_{RBC}}{c}\right)^2 - f_0$$

$$= 2f_0\left(\frac{V_{RBC}}{c}\right) + f_0\left(\frac{V_{RBC}}{c}\right)^2 \qquad \ldots(7)$$

since $V_{RBC} << C$

$$f_D = \left(2f_0\frac{V_{RBC}}{C}\right) \qquad \ldots(8)$$

The relative velocity (to be indicated as v_r) between the red blood cell and the transducer is dependent on the angle of a straight line (the line down which the sound is traveling) and the red blood cell and the direction of the red blood cell motion as shown in Fig.(3).

In other words, if the red blood cell were traveling directly toward the transducer (or directly away), the relative velocity would be at a maximum (or the negative maximum). When cosine 0° =1, $v_r = v_{RBC}$ at 0°. When cosine 180°=1, $v_r = v_{RBC}$ at 180°. Since cosine 90° =0, v_r = 0 at 90°. This relationship can also be written as $v_r = v_{RBC} * \cos\theta$, where the angle is indicated in Fig (2). Plugging this relationship into Equation 8, the Doppler equation can be obtained [7]:

$$f_D = \Delta f = \left(2 \cdot f_o \cdot \frac{V_t}{c}\right) = \frac{2 \cdot f_0 \cdot V_{RBC} \cdot \cos\theta}{C} \qquad \ldots(9)$$

$$V_{RBC} = \frac{f_D \cdot c}{2 \cdot f_0 \cdot \cos\theta} = \left(\frac{f' - f_o}{f_o}\right) \cdot \frac{C}{2 \cdot \cos\theta} \qquad \ldots(10)$$

f_D = Doppler shift frequency that is affected by the density of the particles (red blood cell) in the blood vessel.
v_{RBC} = the velocity of blood in the vessel.
f_o = transmitted frequency.
c = the velocity of the sound in the blood.
θ = Doppler angle.

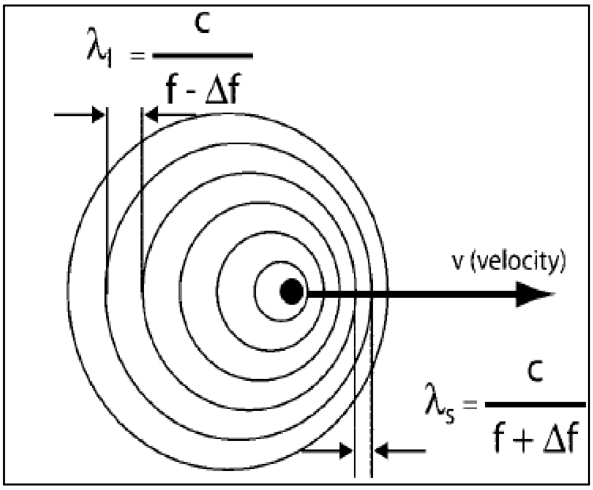

Fig. 2. As an Object Emitting Sound Moves at a Velocity *v*, the Wavelength of the Sound in the Forward Direction is Compressed (s) and the Wavelength of the Sound in the Receding Direction is Elongated (l), *c* = Sound Speed [7].

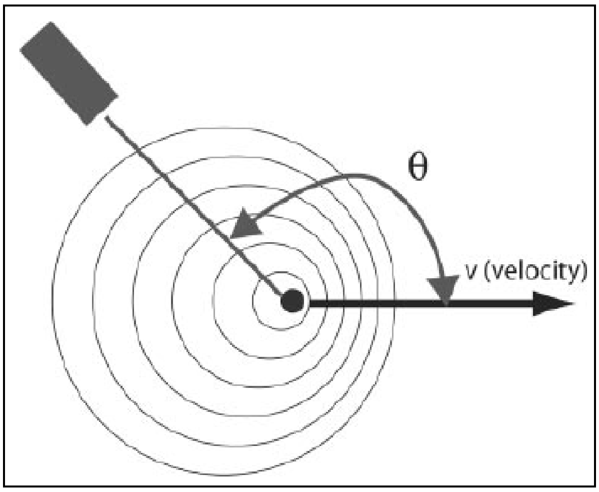

Fig. 3. The Velocity of Red Blood Cells Relative to the Position and Angle of the Transducer Depends on the Angle (Ө) between the Direction of Sound Propagation and the Motion of the Particle [7].

3. Experimental Work

This work was done on a subject that has normal blood vessels history whose age is 30 years old, and on an abnormal subject that have a problem of carotid stenosis; his age was 38 years old. The Doppler device was applied to each one of them in Yarmuk teaching hospital. This device which has a linear probe of 4 -12 MHz frequency was applied to the subject body after putting ultrasonic gel on his skin, in order to make the movement of the probe more easier and the transmission of the ultrasonic wave better, the blood flow velocity was measured by placing the probe (A highly loaded lead zirconate titanate ultrasonic transducer is usually used for this purpose) of the ultrasonic Doppler device on the large arteries (abdominal aorta and carotid artery in the neck), large veins (the inferior vena cava across the abdomen and the external Jugular vein in the neck) , and the capillaries of the hand and fingers. At each type of these five different blood vessels, the Doppler shift frequency was calculated by making the ultrasonic device using a band of transmitted frequencies toward each type of vessels and using different probes angles for each frequency transmitted. After getting the velocity of the blood flow for each vessel of the two subject from the device, the Doppler shift frequency can be calculated from equation (10) by using Mathlab program, in order to prove that the Doppler frequency is dependent on:

1. Blood Velocity: As velocity increases, the shifted Doppler frequency increases also as shown in Table (1) [8].
2. Ultrasound Frequency: Higher ultrasound frequencies give less depth of Penetration, and lower ultrasound frequencies have better penetration. This is due to the fact that the wavelength is inversely proportional to frequency, the frequency transmitted ranges between 2MHz and 12MHz, and Table (2) shows the best range of frequencies used in vascular region [9].
3. Doppler Angle: The Doppler frequency increases as the Doppler ultrasound beam becomes more aligned to the flow direction (the angle θ between the beam and the direction of flow becomes smaller) this is of the most importance in the use of Doppler ultrasound, as explained by Fig. (4) [10].
4. Direction of Blood Flow: If the flow of blood has the same direction as the ultrasonic beam, then it is considered that the blood is flowing away from the transducer. In this case, the Doppler shift frequency is lower than zero, and when the blood flow is opposite to the direction of the ultrasonic beam, it is greater than zero [11].
5. Ultrasound Probe: There are different types of transducers which are used with the ultrasound system; these are curved, phased, and linear. The curved and phased are not used in vascular application, the linear probe is vascular probe and used for measuring blood flow in the vessels.

Table 1,
Normal Blood Flow Velocities in Different Types of Blood Vessels [8].

Blood vessel	**Diameter (cm)**	**Velocity (cm\sec)**
Capillary	0.0005- 0.001	0.005-0.1
Large arteries	2-60	20-25
Large veins	0.5-1	15-20

Table 2,
The Transmitted Frequencies that are used to Measure Blood Flow According to Depth [9].

Application and depth	**7 MHz-12 MHz**	**4MHz-7MHz**
Vascular (0-3cm depth)	Best	Better
Vascular (3-8cm depth)	Better	Best

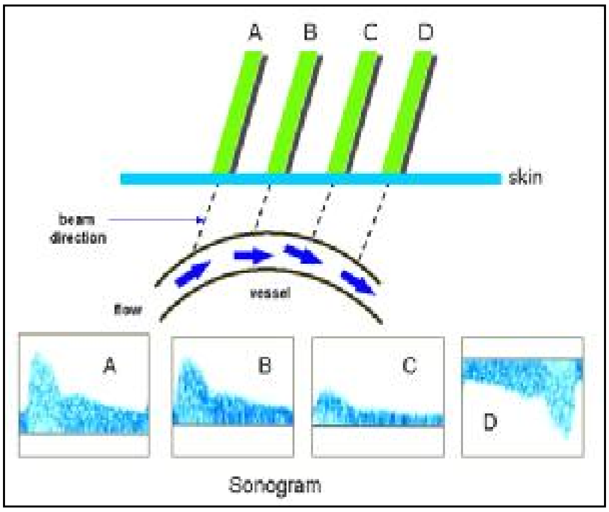

Fig. 4. Effect of the Doppler Angle in the Sonogram. (A) Higher-Frequency Doppler Signal is obtained if the Beam is aligned more to the Direction of Flow. In the Diagram, Beam (A) is more aligned than (B) and Produces Higher-Frequency Doppler Signals. The Beam/Flow Angle at (C) Is Almost 90° and there is a Very Poor Doppler Signal. The Flow at (D) Is Away from the Beam and there is a Negative Signal [11].

4. Results and Discussion

4.1. Doppler Effect with Normal Subject

Since the Doppler shift frequency represent, a change or shift in the frequency of the returning echoes compared to the frequency of the transmitted ultrasound waves [Fd= Fr-Ft] as shown in Tables [3,4,5,6&7], the Doppler shift frequency have a higher magnitudes (greater than zeroes) and a positive polarity [2,11], which means that the blood flow in these vessels is opposite to the direction of an ultrasonic beam emitted from the transducer, and the echoes reflected back from blood cells flowing towards the ultrasonic transducer giving values greater than zero and positive polarity [3]. Table (3) represents Values of Doppler shift frequency in Carotid artery for normal subject. As an example, if the transmitted frequency is 7 MHz, and Doppler angle is 30^o ,the measured velocity from the device was 15.45 cm/sec, then by using equation (10) the Doppler shifted frequency will be 1.2 KHz , which is greater than zero; blood flow is opposite to the direction of an ultrasonic beam emitted from the transducer, and the echoes that reflected back from blood cells flowing towards the transducer. at the same transmitted frequency (7 MHz) ,with Doppler angle 45^o ,60^o, the measured velocity will be 19.07,19.2 cm/sec respectively, which means that the velocity of blood flow increases as Doppler angle increases at the same transmitted frequency until it reaches 37.1 cm /sec at 75 ^{o} ,while the shifted Doppler frequency will be at 45 ^{o} 1.208khz while at 60 ^{o},75 ^{o} it will be 0.86,0.85khz, respectively. These different changes in the values of the shifted Doppler frequency are at the same transmitted frequency because the movement of the blood cells in the vessels is in circular groups with laminar flow, so the transducer will emit the same frequency to each group of cell but receive different echoes magnitude from the cells according to their distance from the transducer, so there will be different Doppler shift frequency as shown in Tables (3, 4, 5, 6, &7).

It is important to understand the Doppler shift frequency since some of the ultrasonic Doppler device gives only the Doppler shift frequency then by using Doppler mathematical model in Equation (10), the blood flow velocity can be determined.

From the graphical representations of the normal subject found in Figures (5), the velocity of blood flowing in the carotid artery was found. The transmitted frequencies wear 7,8,10,&12Mhz which has been selected to measure blood flow according to the depth of this vessel as shown in Table(2) [9]. At each one of these transmitted frequencies, there are three different reigns of angles. This figure shows nearly linear relationship between velocity and Doppler angle. The first liner region is between 30° to 45°, where the velocity is lower than normal physiological reference which is 20-25 cm/sec in large artery. At angles between 45° to 60°, there is another linear region that that differs from the first region where the velocity is almost the same as that of the normal physiological reference 20-25 cm/sec. The third linear region at angles between 60-75° the velocity is much higher than normal physiological references. so Figure(5) shows that in order to get the most accurate measure for velocity of blood flow in carotid artery, so during the investigation of the subject the Doppler ultrasound system's probe needs a modification for the Doppler angle to be between 45°and 60° between the probe of the device and the vessel direction.

From the graphical representations of the normal subject found in Figure (6) the velocity of blood flowing in Aorta, was found. The transmitted frequencies 4,5,6,&7Mhz which wear selected to measure blood flow according to the depth of this vessel as shown in Table(2) [9]. Each one of these transmitted frequencies, there are three different reign of angles. This figure shows nearly linear relationship between velocity and Doppler angle. The first liner region is between 30° to 45°, where the velocity is lower than normal physiological reference which is 20-25 cm/sec in large artery. At angles between 45° to 60,° there is another linear region that differs from the first region where the velocity is almost the same as that of the normal physiological reference 20-25 cm/sec. The third linear region is at angles between 60-75°. The velocity is much higher than normal physiological references. So Figure(6) shows that during the investigation of the subject the Doppler ultrasound system's probe must be aligned at an angle between 45°and 60° between the probe of the device and the vessel direction to get the accurate velocity measurement and diagnosis.

From the graphical representations of the normal subject found in Figure (7) the velocity of blood flowing in the large vein (Inferior Vena Cava) was found. The transmitted frequencies ware 4,5,6,&7Mhz which were selected to measure blood flow according to the depth of this vessel as shown in Table(2) [9]. At each one of these transmitted frequencies, there are three different reign of angles in this figure shows nearly linear relationship between velocity and Doppler angle. The first liner region is between 30° to 45°, where the velocity is lower than normal physiological reference which is 15-20 cm/sec in large artery; At angles between 45° to 60° there is another linear region differ from the first region where the velocity is almost the same as that of the normal physiological reference 15-20 cm/sec. The third linear region is at angles between 60-75° .The velocity is much higher than 15-20 cm/sec. So Figure(7) shows that during the investigation of the subject the Doppler ultrasound system's probe must be aligned at an angle between 45°and 60° between the probe of the device and the vessel direction to get the accurate velocity measurement and diagnosis.

From the graphical representations of the normal subject that found in Figure (8) the velocity of blood flowing in the external jugular Vena Cava was found. That the transmitted frequencies 7,8,10,&12Mhz which were selected to measure blood flow according to the depth of this vessel as shown in Table(2) [9]. At each one of these transmitted frequencies, there are three different reign of angles. This figure shows nearly linear relationship between velocity and Doppler angle ,the first liner region is between 30° to 45°, where the velocity is lower than normal physiological reference which is 15-20 cm/sec in large artery. At angles between 45° to 60° there is another linear region that differs from the first region where the velocity is almost the same as that of the normal physiological reference 15-20 cm/sec. The third linear region at angles between 60-75° the velocity is much higher than normal physiological references. So Figure (8) shows that the Doppler angle of the probe must be aligned to be between 45°and 60° with the vessel direction.

From the graphical representations of the normal subject found in Figure (9) the velocity of blood flowing in the capillary was found. The transmitted frequencies are 7,8,10,&12Mhz which were selected to measure blood flow according to the depth of this vessel as shown in Table(2) [9]. at each one of these transmitted frequencies, there are three different reign of angles in this figure shows nearly linear relationship between velocity and Doppler angle. The first liner region is between 30° to 45°, where the velocity is lower than normal physiological reference which is 15-20 cm/sec in large artery; At angles between 45° to 60° there is another linear region differ from the first region where the velocity is almost the same as that of the normal physiological reference which is 15-20 cm/sec. The third linear region at angles between 60-75° the velocity is much higher than normal physiological references. So Figure (9) shows that the Doppler angle of the probe must be aligned to be between 45°and 60° with the vessel direction.

Table 3,
Values of Doppler Shift Frequency in Carotid Artery for Normal Subject.

Transmitted Frequency (Ft MHz)	Doppler Angle(Ө)	The measured Velocity (V cm/sec)	Doppler Shifted Frequency (calculated) (Fd KHz)
7	30	15.45	1.20
7	45	19.07	1.208
7	60	19.20	0.86
7	75	37.1	0.85
8	30	9.36	0.83
8	45	15.20	1.10
8	60	20.00	1.02
8	75	32.43	0.85
10	30	14.18	1.57
10	45	16.27	1.47
10	60	19.89	1.27
10	75	37.03	1.22
12	30	15.10	2.01
12	45	16.20	1.76
12	60	20.09	1.54
12	75	37.80	1.50

Table 4,
Values of Doppler Shift Frequency in Aorta for Normal Subject.

Transmitted Frequency (Ft MHz)	Doppler Angle(Θ)	The measured Velocity (V cm/sec)	Doppler Shifted Frequency (calculated) (Fd KHz)
7	30	11.7	0.90
7	45	17.07	1.08
7	60	23.60	1.05
7	75	36.10	0.83
6	30	12.20	0.81
6	45	19.07	1.03
6	60	24.68	0.94
6	75	36.17	0.71
5	30	14.70	0.81
5	45	21.25	0.96
5	60	25.50	0.81
5	75	38.87	0.64
4	30	15.18	0.67
4	45	20.27	0.73
4	60	25.30	0.64
4	75	37.0	0.48

Table 5,
Values of Doppler Shift Frequency in External Jugular Vena Ceva for Normal Subject.

Transmitted Frequency (Ft MHz)	Doppler Angle(Θ)	The measured Velocity (V cm/sec)	Doppler Shifted Frequency (calculated) (Fd KHz)
7	30	9.77	0.74
7	45	11.50	0.72
7	60	14.93	0.64
7	75	27.64	0.63
8	30	10.08	0.89
8	45	11.47	0.83
8	60	15.28	0.78
8	75	26.60	0.70
10	30	11.25	1.24
10	45	12.68	1.14
10	60	14.82	0.95
10	75	26.60	0.87
12	30	11.67	1.55
12	45	13.08	1.51
12	60	15.12	1.16
12	75	27.60	1.07

Table 6,
Values of Doppler Shift Frequency in Inferior Vena Ceva for Normal Subject.

Transmitted Frequency (Ft MHz)	Doppler Angle(Θ)	The measured Velocity (V cm/sec)	Doppler Shifted Frequency (calculated) (Fd KHz)
7	30	10.47	0.81
7	45	12.90	0.81
7	60	16.90	0.75
7	75	27.60	0.70
6	30	11.82	0.77
6	45	13.50	0.73
6	60	17.11	0.65
6	75	27.79	0.59
5	30	11.80	0.65
5	45	13.90	0.62
5	60	18.68	0.59
5	75	28.95	0.47
4	30	11.80	0.49
4	45	13.97	0.50
4	60	18.02	0.46
4	75	28	0.37

Table 7,
Values of Doppler Shift Frequency in Capillary for Normal Subject.

Transmitted Frequency (Ft MHz)	Doppler Angle(Θ)	The measured Velocity (V cm/sec)	Doppler Shifted Frequency (calculated) (Fd KHz)
7	30	0.033	0.0045
7	45	0.039	0.0043
7	60	0.049	0.0038
7	75	0.085	0.0034
8	30	0.037	0.0042
8	45	0.040	0.0037
8	60	0.050	0.0032
8	75	0.087	0.0029
10	30	0.042	0.0038
10	45	0.045	0.0033
10	60	0.048	0.0025
10	75	0.183	0.0022
12	30	0.038	0.0030
12	45	0.037	0.0024
12	60	0.042	0.0019
12	75	0.056	0.0013

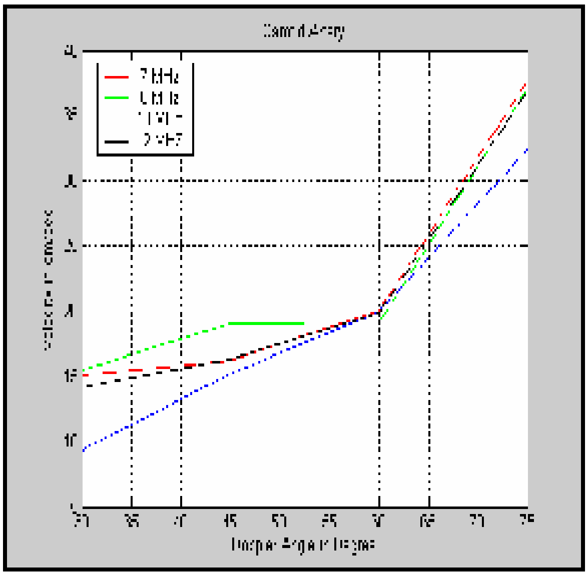

Fig. 5. The Velocity of the Blood Flow versus the Doppler Angle in Carotid Artery for Different Frequencies [7, 8, 10, 12 MHz] for Normal Subject.

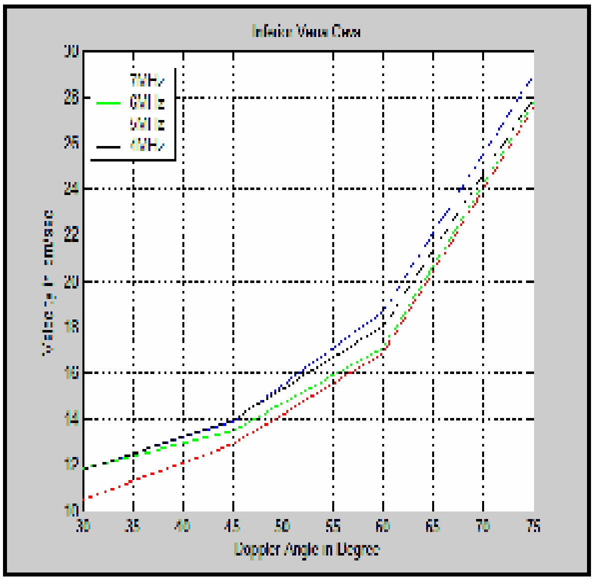

Fig. 7. The Velocity of the Blood Flow versus the Doppler Angle in Large Vein (Inferior Vena Ceva) for Different Frequencies [4, 5, 6,7MHz] for Normal Subject.

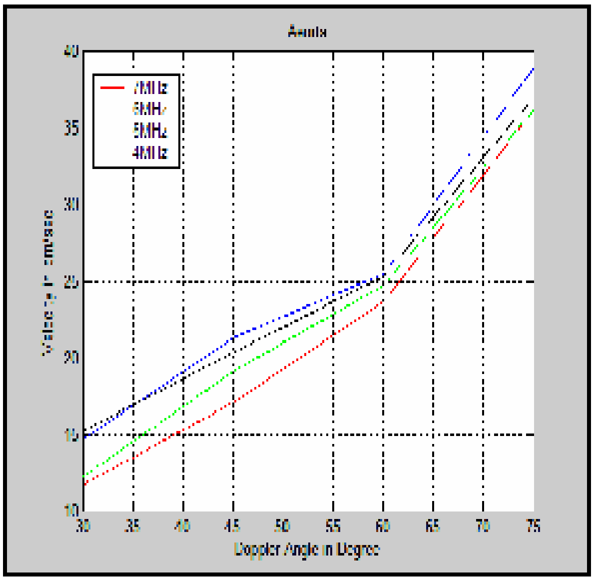

Fig. 6. The Velocity of the Blood Flow versus the Doppler Angle In Aorta for Different Frequencies [4, 6, 5,7MHz] for Normal Subject.

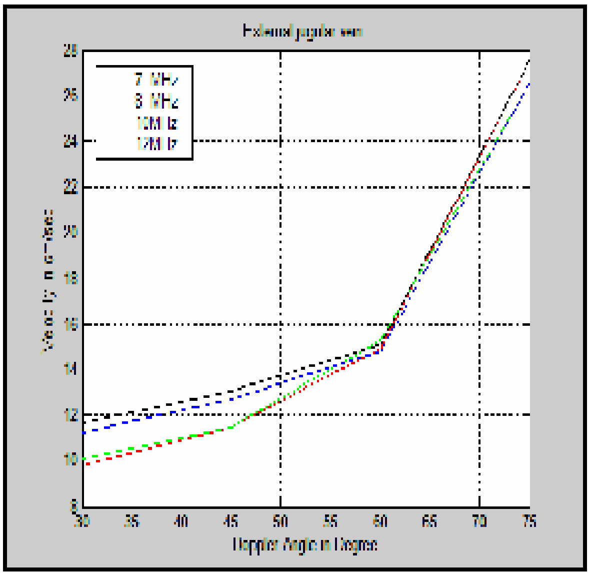

Fig. 8. The Velocity of the Blood Flow versus the Doppler Angle in External Jugular Vein for Different Frequencies [7, 8, 10, 12 MHz] for Normal Subject.

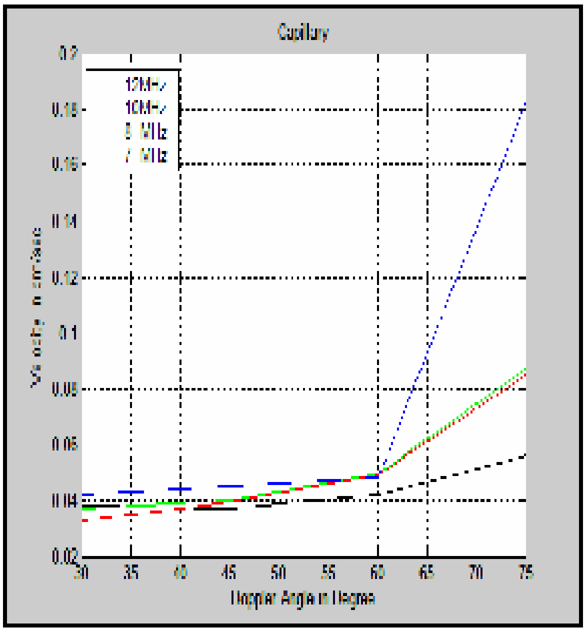

Fig. 9. The Velocity of the Blood Flow versus the Doppler Angle in Capillary for Different Frequencies [7, 8, 10, 12MHz] for Normal Subject.

4.2. Doppler Effect with Abnormal Subject

The Doppler shift frequency for abnormal subject shown in Tables (9,10,11,&12) is the same as that found with normal person except for that found in Table (8) which indicates there is a stenosis in the carotid artery where the region at the Doppler angle between 45-60^{o} the velocity decreased gradually until it reached sever stenosis at 60 degree where blood flowing was obstructed by narrowing of the artery which is usually caused by the buildup of fatty substances and cholesterol deposits, called plaque. So as the velocity decreased, the Doppler shift frequency decreased also. For example, at 7MHz (45^{o}was 1.291& 60^{o} was 0.736), at 8MHz (45^{o}was 1.41 KHz& 60^{o} was 1.02 KHz), at 10MHz (45^{o}was 2.4 KHz & 60^{o} was 0.98 KHz), at12 MHz (45^{o}was 2.19 KHz & 60^{o} was 1.3 KHz). This high decrease in the Doppler shift magnitudes is consider as an indication for the presence of turbulent flow, where the presence of stenosis increases the value of echoes received by the transducer, so the shift frequency will be reduced.

From the graphical representations of the abnormal subject (undergoes stenosis in the carotid artery) that found in Figure (10), the velocity of blood flowing in the carotid artery was found. The transmitted frequencies are 7,8,10,&12Mhz which has been selected to measure blood flow according to the depth of this vessel as shown in Table(2) [9]. At each one of these transmitted frequencies, there are three different reign of angles. This figure shows nearly linear relationship between velocity and Doppler angle, the first liner region is between 30° to 45°, where the velocity is almost the same as that of the normal physiological reference which is 20-25 cm/sec and there is no appearance or indication for any abnormal flow. At angles between 45° to 60°, there is another linear region differed from the first region where the velocity at 7 MHz (45^{o} was 20.09 cm/sec,60^{o} ,was 16.2 cm/sec) ,at 8MHz (45^{o} was 19.20 cm/sec,60^{o} was 20 cm/sec),at 10MHz (45^{o} was 20 cm/sec,60^{o} was 15.2 cm/sec), at 12MHz (45^{o} was 19.89 cm/sec,60^{o} was 16.7cm/sec).Obviously in this region (45 ^{o} -60^{o}) when compared with normal person, at each transmitted frequency, the velocity of the blood decreased gradually until it reached lower value than that of the normal physiological references that were 20-25 cm/sec since the diameter of the artery decreased gradually making blood flow turbulent. So this is an indication for the appearance of problem of stenosis, the third linear region at angles between 60-75°. The velocity is very much higher than normal physiological references. So in order to get the most accurate measurement for velocity of blood flow in carotid artery and to get best diagnosis for the stenosis artery, the Doppler ultrasound system's probe needs a modification for the Doppler angle to be between 45°and 60° between the probe of the device and the vessel direction.

All the graphical representations found in Figures (11,12,13,&14) when compared with normal subject have the same characteristic found in the normal subject ,which means that there is no disease in these vessels.

Table 8,
Values of Doppler Shift Frequency in Carotid Artery for Abnormal Subject.

Transmitted Frequency (Ft MHz)	Doppler Angle(Θ)	The measured Velocity (V cm/sec)	Doppler Shifted Frequency (calculated) (Fd KHz)
7	30	15.45	1.20
7	45	20.09	1.291
7	60	16.20	0.736
7	75	37.1	0.85
8	30	9.36	0.83
8	45	19.20	1.41
8	60	37.00	1.02
8	75	32.43	0.85
10	30	14.18	1.57
10	45	20	2.4
10	60	15.2	0.98
10	75	37.03	1.22
12	30	15.10	2.01
12	45	19.89	2.19
12	60	16.7	1.3
12	75	37.80	1.50

Table 9,
Values of Doppler Shift Frequency in Aorta for Normal Subject.

Transmitted Frequency (Ft MHz)	Doppler Angle(Θ)	The measured Velocity (V cm/sec)	Doppler Shifted Frequency (calculated) (Fd KHz)
7	30	11.7	0.90
7	45	17.07	1.08
7	60	23.60	1.05
7	75	36.10	0.83
6	30	12.20	0.81
6	45	19.07	1.03
6	60	24.68	0.94
6	75	36.17	0.71
5	30	14.70	0.81
5	45	21.25	0.96
5	60	25.50	0.81
5	75	38.87	0.64
4	30	15.18	0.67
4	45	20.27	0.73
4	60	25.30	0.64
4	75	37.0	0.48

Table 10,
Values of Doppler Shift Frequency in External Jugular Vena Ceva for Abnormal Subject.

Transmitted Frequency (Ft MHz)	Doppler Angle(Θ)	The measured Velocity (V cm/sec)	Doppler Shifted Frequency (calculated) (Fd KHz)
7	30	9.77	0.74
7	45	11.50	0.72
7	60	14.93	0.64
7	75	27.64	0.63
8	30	10.08	0.89
8	45	11.47	0.83
8	60	15.28	0.78
8	75	26.60	0.70
10	30	11.25	1.24
10	45	12.68	1.14
10	60	14.82	0.95
10	75	26.60	0.87
12	30	11.67	1.55
12	45	13.08	1.51
12	60	15.12	1.16
12	75	27.60	1.07

Table 11,
Values of Doppler Shift Frequency in Inferior Vena Cava for Abnormal Subject.

Transmitted Frequency (Ft MHz)	Doppler Angle(Θ)	The measured Velocity (V cm/sec)	Doppler Shifted Frequency (calculated) (Fd KHz)
7	30	10.47	0.81
7	45	12.90	0.81
7	60	16.90	0.75
7	75	27.60	0.70
6	30	11.82	0.77
6	45	13.50	0.73
6	60	17.11	0.65
6	75	27.79	0.59
5	30	11.80	0.65
5	45	13.90	0.62
5	60	18.68	0.59
5	75	28.95	0.47
4	30	11.80	0.49
4	45	13.97	0.50
4	60	18.02	0.46
4	75	28	0.37

Table 12,
Values of Doppler Shift Frequency in Capillary for Abnormal Subject.

Transmitted Frequency (Ft MHz)	Doppler Angle(Θ)	The measured Velocity (V cm/sec)	Doppler Shifted Frequency (calculated) (Fd KHz)
7	30	0.033	0.0045
7	45	0.039	0.0043
7	60	0.049	0.0038
7	75	0.085	0.0034
8	30	0.037	0.0042
8	45	0.040	0.0037
8	60	0.050	0.0032
8	75	0.087	0.0029
10	30	0.042	0.0038
10	45	0.045	0.0033
10	60	0.048	0.0025
10	75	0.183	0.0022
12	30	0.038	0.0030
12	45	0.037	0.0024
12	60	0.042	0.0019
12	75	0.056	0.0013

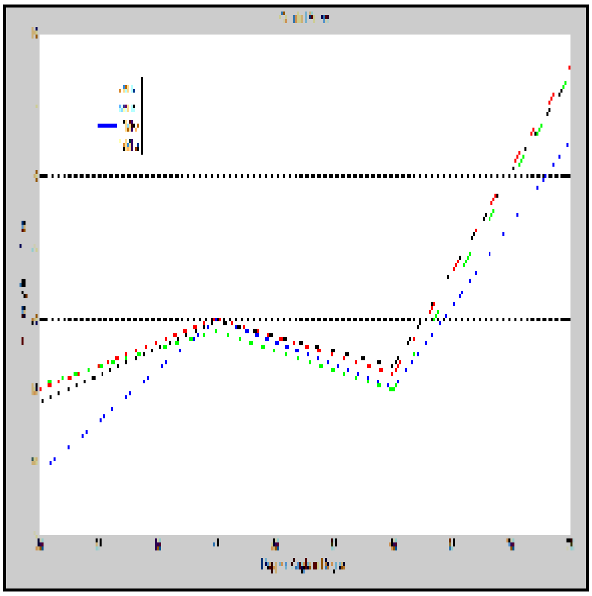

Fig. 10. The Velocity of the Blood Flow versus the Doppler Angle in Carotid Artery for Different Frequencies [7, 8, 10, 12 MHz] for Abnormal Subject.

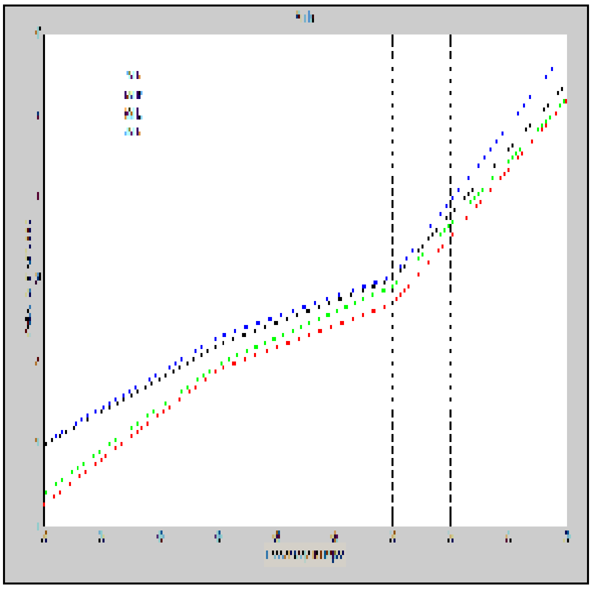

Fig. 11. The Velocity of the Blood Flow versus the Doppler Angle in Aorta for Different Frequencies [4, 6, 5,7MHz] for Abnormal Subject Subject.

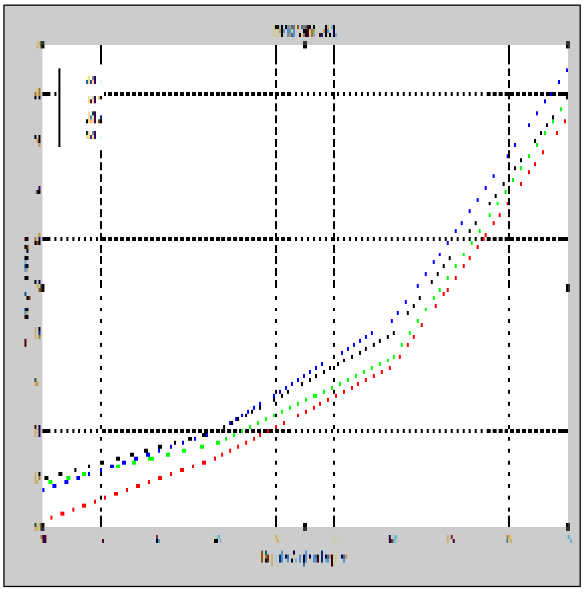

Fig. 12. The Velocity of the Blood Flow versus the Doppler Angle in Large vein (Inferior Vena Cevan for Different Frequencies [4, 5, 6,7MHz] for Abnormal Subject.

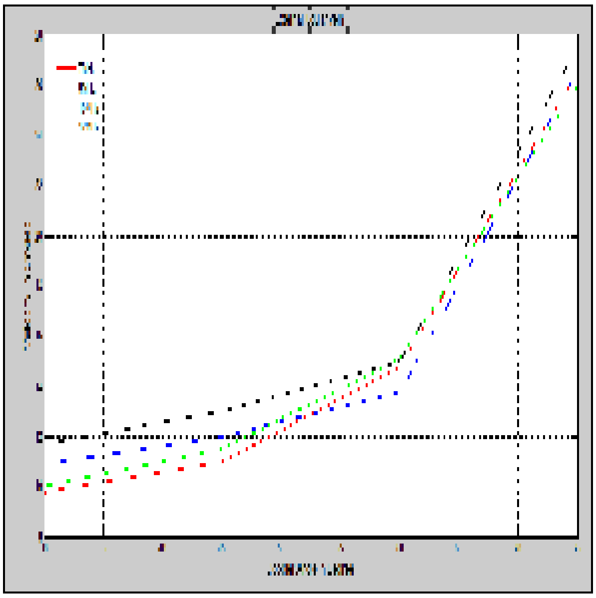

Fig. 13. The Velocity of the Blood Flow versus the Doppler Angle in External Jugular vein for Different Frequencies [7, 8, 10, 12 MHz] for Abnormal Subject.

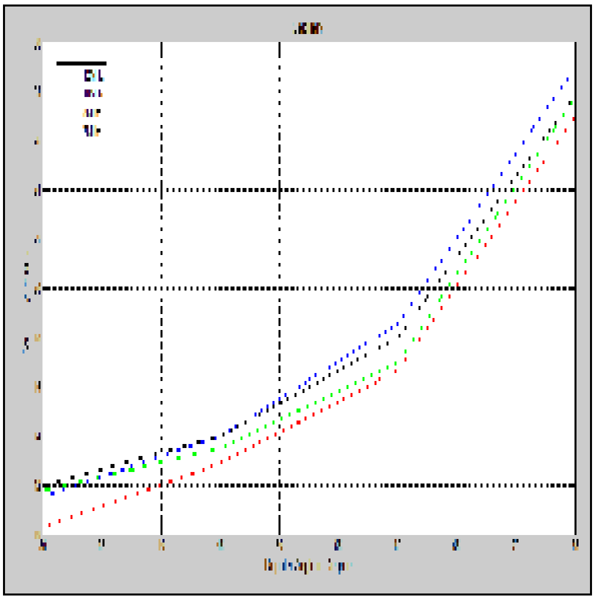

Fig. 14. The Velocity of the Blood Flow versus the Doppler Angle in Capillary for Different Frequencies [7, 8, 10, 12MHz] for Abnormal Subject.

5. Conclusions

1. The size of the Doppler signal is dependent on blood velocity, as velocity increases, so does the Doppler frequency.
2. In the Doppler ultrasound, the penetration depth in the human body is inversely proportionate with the transmitted frequencies as explained in Table (2).The relationship between shifted Doppler frequencies and Doppler angles is nearly linear for each group of Doppler angles. As the Doppler angle increases the shifted Doppler frequency decreases and vice versa.
3. Transmitted frequencies have great effect on shifted Doppler frequencies and on measured Velocities. As transmitted frequency increases the shifted Doppler frequency and measured velocities increase and vice versa.
4. The Doppler ultrasound system's probe needs a modification for the angle to be between 45°and 60° between the probe and the vessel direction to give the most accurate measure.
5. The Doppler ultrasound can measure the blood flow in all types of blood vessels, arteries, veins, but to less extent the capillaries as the scattered frequency from them is very small and inaudible.
6. Doppler methods can be used for the evaluation of normal and abnormal flow states and provides quantitative data that are essential in the clinical decision .making process concerning patients with heart disease.

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مدى تأثير ظاهرة دوبلر على سرعة تدفق الدم

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الخلاصة

هذا البحث يعتمد دراسة ظاهرة دوبلر(تردد دوبلر) كطريقة يتم من خلالها قياس اتجاه وسرعة جريان خلايا الدم في الاوعية الدموية، حيث أن هذا التردد تم الاعتماد علية طبيا في قياس سرعة جريان الدم، اذ ان جريان الدم يعتبر مفهوما مهما من مفاهيم الطب فهويمثل وظيفة وكفأة القلب والأوعية الدموية في الجسم لذلك فأن اي خلل في هذه الوظيفة سيظهر كتغيير في سرعة جريان الدم عن القيمة الطبيعية المفترضة، اذ ان هذة السرعة تتغير كثيرا في حالات المرض اوالاعتلال القلبي، ولاجل التعرف على تأثيرتغيير تردد دوبلر على سرعة جريان الدم وعلاقة هذا التردد مع زاويا الارسال والاستلام وتأثير تغيير تردد الموجة فوق الصوتية المرسلة على السرع المقاسة تم استخدام جهاز الدوبلر فوق السمعي كونة الجهاز الأكثر كفأءة والأسهل استعمالا كتطبيق عملي في مستشفى اليرموك التعليمي على شخصين أحدهما طبيعي يمتلك تاريخ طبي طبيعي في الاوعية الدموية، والأخر غير طبيعي يمتلك ضييق في الشريان السباتي، حيث يقوم هذا الجهاز بتزويدنا بسرعة جريان الدم في الأوعية الدموية وهي التي تهم الفاحص ، لذلك قمنا بأعتماد معادلة دوبلر كموديل رياضي في بحثنا للأستفادة من هذه السرعة المقاسة في توضيح مقدار التغيير في التردد (shift in frequency) ،علما ان هذة السرعة تم قياسها في خمسة أوعية دموية مختلفة، الشرايين الكبيرة (الابهر البطني والشريان السباتي في العنق) والأوردة الكبيرة (الوريد الأجوف السفلي في جميع أنحاء البطن والوريد الوداجي الخارجي في الرقبة) والشعيرات الدموية في اليد والأصابع، ثم باستخدام السرع المقاسة في هذه الأوعية المختلفة تم حساب تردد دوبلر من النموذج الرياضي باستخدام برنامج MATLAB ، حيث وجد انه كلما زادت سرعة جريان الدم حصل ازدياد في قيمة تردد دوبلر والعكس بالعكس، وكلما زادت قيمة زاوية دوبلر المستخدمة في الجهاز حصل نقصان في تردد دوبلر والعكس بالعكس، وكذلك الترددات المستخدمة في الارسال كلما زادت قيمتها حصل ازدياد في سرعة جريان الدم وفي تردد دوبلر والعكس بالعكس، ومن خلال الدراسة تم ملاحظة انه من الممكن الحصول على سرعة جريان الدم في الاوعية الدموية المختلفة الشرايين والأوردة بسهولة ولكن بمدى قليل في الاوعية الشعرية كون الترددات المستلمة ذات قيمة صغيرة جدا.