Doppler ultrasound

The scientific principle behind a medical application

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Abstract

Doppler ultrasound is a medical application that exploits the majesty of physics principles to enhance our world. It enabled physicians and doctors to intensify their applicability of obtaining data about the patient, so they reach the most desired level of accuracy in examination and diagnoses. This application uses the scientific foundation of the Doppler effect to give clarifying images for the flow of blood inside the vessels and arteries. By analyzing test's results, doctors can check the blocked vessels in our blood and identify the reason for some diseases like secondary blood pressure. In addition, the application has many types varying in their operating procedures, and each one of them accomplish a specific purpose. This literature review article is a quick walkthrough between the main headlines that are related to the Doppler ultrasound technology from its scientific principle, general uses, and the most important types of it.

Keywords: Doppler ultrasound, Doppler effect, Color flowing mapping, Spectral Doppler, Power Doppler, Light spectrum

I. Introduction

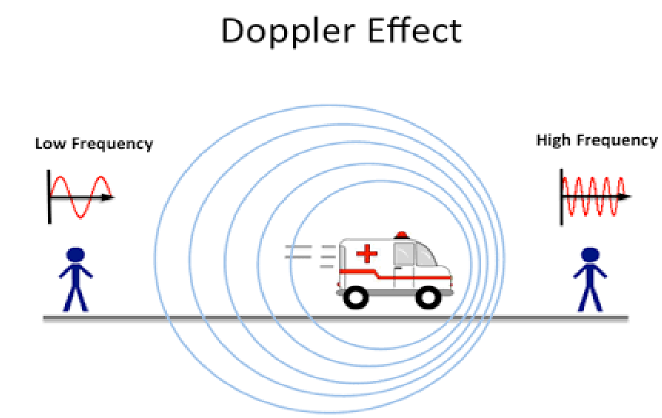
Doppler ultrasound has been showing its efficiency as an application used in the medical blood analysis field. Not only it gives a representation of the structures of the body as the regular ultrasound but also gives an image of the blood flowing through arteries and blood vessels. The analysis has many types differing in the blood feature that is being tested like the speed and direction of the blood, also differing in the accuracy of the test. The analysis is considered totally safe without any type of harm to humans.

The mechanism uses sound waves to image the flowing of the blood through arteries and blood vessels since it operates by measuring the sound waves that are reflected from moving blood cells mainly counting on the doppler effect. Therefore, to understand the scientific base of Doppler ultrasound, we must understand the Doppler effect.

II. What is the doppler effect?

It is the change in the frequency of the waves due to the relative motion between the waves' source and the receiver of the wave or (Observer). In other words, when the emitting-waves body changes its position relative to an observer, the frequency of its waves differs according to the newly approached direction. As shown in figure (1), when the body starts to move, the frequency of the waves intensifies in the direction of approach, and it decreases in the direction of receding.

This phenomenon explains the increase of horn sound when the truck is approaching the observer and the decrease of the same sound when the truck is distancing.



Figure(1): A showcase for the doppler effect in a truck's horn.

The change in frequency that results from the doppler effect can be determined by the following equation:

$$f' = f\frac{v \pm vD}{v \pm vS}$$

where *v* is the sound speed throughout the air, *vD* is the speed of the detector relative to the air, and *vS* is the speed of the source relative to air. Choosing either plus or minus signs is determined by the following rule: When the motion of either the detector or the source is toward each other the sign of the speed must result in an upward frequency shift. On the other side, when their motion is away from each other, the sign of the speed must result in a downward frequency shift. [1]

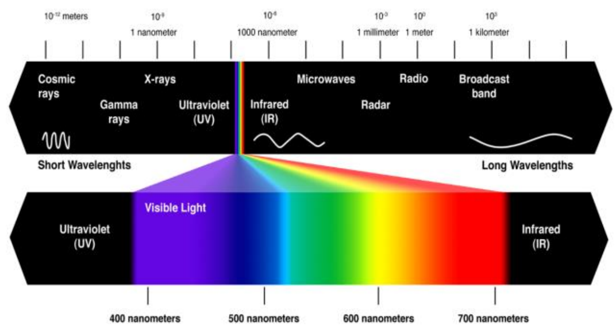
The f' is the resultant frequency that is expressed by the observer, and it shifts either upward or downward according to the motion direction relative to the observer.

Reliance on the equation, $v = \frac{c}{\lambda}$, it can be deduced that there is an inverse relationship between the frequency and the wavelength.

In consequence, whereas the doppler effect is responsible for changing the frequency of the waves, their wavelengths change.

Furthermore, the changing of wavelengths according to the light spectrum phenomenon shown in figure (2) causes the visible light waves to change their color.

This can result in changing the color of moving bodies that emit visible light waves due to



Figure(2): The light spectrum

changing their frequency through the doppler effect.

Based on this scientific principle of the doppler effect, the Doppler ultrasound mechanism was created.

III. How does the Doppler ultrasound rely on the Doppler effect?

According to Helen Routh in her research: Doppler ultrasound - The ability to measure and image blood flow [2], the Doppler effect is the main principle on which the diagnostic ultrasound examination operates. The Doppler effect occurs when sound waves are reflected from the moving scatterers and in this case, they are blood cells. This can be separated into two different main effects.

These effects are transmission and receiving.

On transmission the wave source is stationary and the observer, in this case, the scatterer, is moving. While on receiving, the source is moving, and the observer is stationary.

Considering a single scatterer, a blood cell moves with velocity, v, and at an angle, θ , with respect to the transmitted beam from the doppler ultrasound device. If the speed of sound from the surrounding area is c, and the frequency transmitted from the device is fo, the opposite changes in the wavelengths will cause the received signal to be shifted by frequency fd. This can be illustrated in the following equation:

$$\boldsymbol{f\mathrm{o} + f\mathrm{d} = f\mathrm{o}\frac{(c + v\cos(\theta\ )}{(c - v\cos(\theta\ )}}$$

therefore, as an inference from the general law of Doppler effect, it can be concluded that the resultant frequency will be equal to the transmitted frequency from the device plus the frequency shifting.

$$\boldsymbol{f' = f\mathrm{o} + f\mathrm{d}}$$

Besides, by assuming that the speed of sound is 1540m/s, it is supposed that the speed of blood is way much less than the speed of sound. Whereas the regular flowing blood speed is less than 1 m/s and even in diseased bodies, blood can nearly exceed the speed of 10 m/s. Therefore, it can be concluded that the speed of flowing blood (v) is extremely smaller than the speed of surrounding sound (c). Consequently, the previous equation of the doppler effect can be simplified to:

$$\boldsymbol{f\mathrm{d} = \frac{2vf\mathrm{o}\cos(\theta)}{c}}$$

Consequently, through applying the previous equations and knowing that we are dealing with more than one scatterer, the huge amount of the flowing red blood cells, the specified area can be detected. This means rather than a single frequency shift for one scatterer is detected, a spectrum of frequency is shifted and detected, which represents the motion in the specified area for analysis. Figure (3) represents a sample for a doppler ultrasound analysis detecting frequency shifts revealing the flowing of blood. [2]

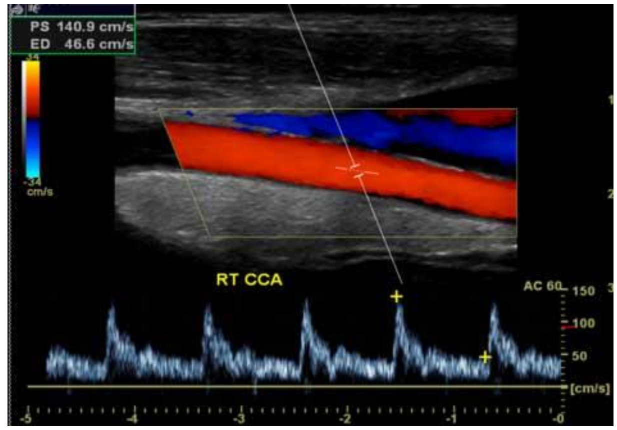


Figure (3): A doppler ultrasound

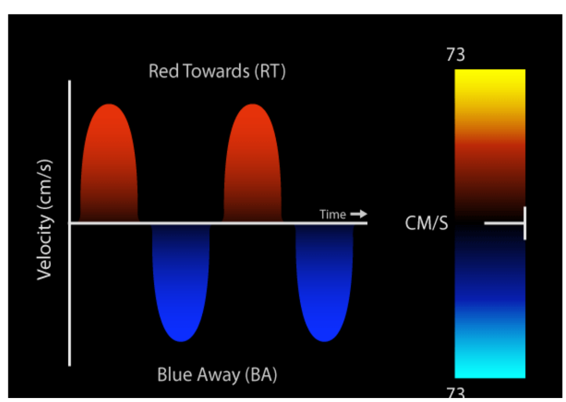
IV. Types of Doppler ultrasound

The mechanism has been evolving for a huge amount of time, enhancing, and increasing the accuracy of the analysis, besides varying its purposes. As a result, many types of the doppler ultrasound device arose and each one of them had its outputs. Some of these types are:

- Doppler color flowing mapping
- Power doppler
- Spectral doppler

On the next page, there is an elaboration for each one of these three Doppler applications.

Firstly, the Doppler color flowing mapping is a procedure that uses inputs from different volumes of pulsed doppler, illustrating the specified part of the analysis in a 2D representation. This representation consists of a colors array showing some of the blood's movement features like direction and velocity. Figure (4) is an example of a Doppler color-flowing mapping report.[3] [4]



Figure(4): A Doppler color flowing mapping

Secondly, the Power doppler is the created technique as an enhancement of the color doppler that exceeds the color doppler in some of its specifications, but on the contrary, loses some of its advancements. The power doppler is capable of giving a more detailed analysis surpassing that of the color doppler. This enables physicians to have images of the blood flowing inside small vessels. These exact images give doctors the chance to ask the patient for a Doppler test to any specified part of the blood vessels regarding their size. A drawback of this technology that it does not provide the direction of blood flowing through the vessels. An illustrating example for a power Doppler report is shown in figure (5)[3]

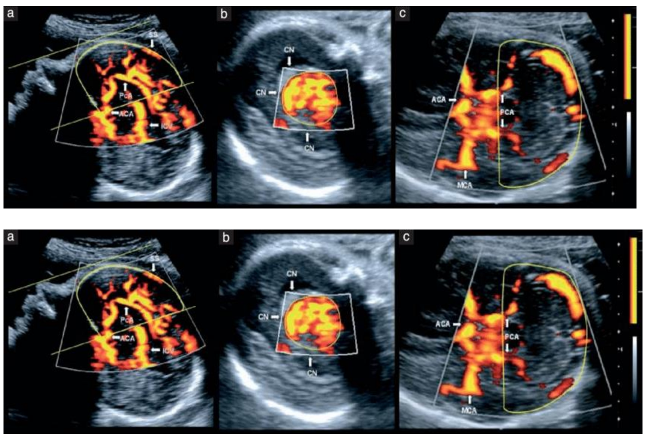
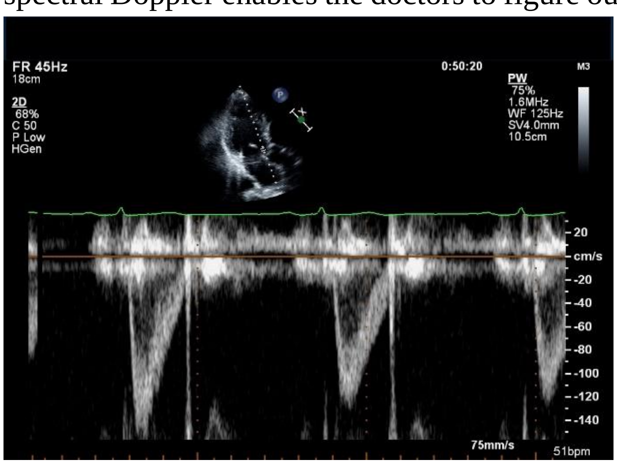


Figure (5): A power Doppler report

Thirdly, the spectral doppler is an illustrative type of doppler ultrasound analysis that provides more information to the physician about the case state, due to its mechanism in presenting the data. As the spectral doppler presents its findings in elaborating graphs that give more detailed information about the patient. In response, the spectral Doppler enables the doctors to figure out some deficiencies that cannot be figured out by the different types of dopplers, and an example of these deficiencies is the number of clogged blood vessels. Figure (6) gives an example of a spectral doppler graph. [4]



Figure(6): A spectral doppler report

V. Conclusion

Overall, it can be inferred that the doppler ultrasound is an important application in the medical field that eases the task of physicians of identifying illness reasons in blood research. The Doppler ultrasound uses the equation of the general law of the doppler effect to reach the intended version of mathematical calculations that can be utilized for medical purposes. Moreover, the Doppler ultrasound shows its benefits by widening its forms. Whereas every type of the Doppler ultrasound mechanism differs from the others in its output, it gives the doctors the ability to decide the analysis's deepness their patients need, so they become able to make the right decision towards the path of curing the people who suffer from illness.

VI. References

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