American Journal of Botany and Bioengineering
https://biojournals.us/index.php/AJBP
ISSN: 2997-9331

Doppler Effect and its Medical Applications

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Received: 2024 20, Jul
Accepted: 2024 20, Aug
Published: 2024 21, Sep

Abstract: The Doppler effect is a physical phenomenon observed when the frequency or wavelength of waves changes when the source of the wave, the receiver, or both moves. This effect is used in many applications, such as measuring the speed of vehicles using radar, determining the speed of blood flow in the body, and analyzing the speed of stars and galaxies. The Doppler effect is divided into two types: the Doppler effect for sound waves, which includes (the approach of the source: the frequency increases, and the sound becomes higher, the distance of the source: the frequency decreases, and the sound becomes lower) and the Doppler effect for electromagnetic waves, which includes (the approach of the source: the frequency increases, and the light becomes blue, the distance of the source: the frequency decreases, and the light becomes red). Applications of the Doppler effect is represented in radar: measuring the speed of vehicles, aircraft, ships, rain, wind. Ultrasound: measuring the speed of blood flow, diagnosing heart diseases, monitoring the development of embryos. Astronomy: measuring the speed of stars and galaxies, discovering exoplanets. Medical applications: measuring the speed of blood flow in blood vessels, diagnosing heart diseases, monitoring blood flow in the brain. Industrial applications: Measuring the speed of fluid flow, monitoring machine vibrations, measuring the speed of movement of materials in production lines. There are limitations to the Doppler effect, namely the relative Doppler effect: It depends on the speed of the source and the direction of its movement relative to the receiver. The Doppler effect is inaccurate: In some cases, the Doppler effect may not be accurate, such as when there are obstacles or reflections of waves. In general, the Doppler effect is an important physical phenomenon that has many applications in different fields. In this research, we presented a study that includes the types of Doppler effect, its applications and the limitations of its use, and we focused in particular on medical applications

Discovery of the Doppler Effect

The Doppler Effect was discovered by the scientist Christian Doppler, an Austrian physicist and mathematician who was appointed professor of physics and mathematics at the Prague College and later became director of the Institute of Physics at the University of Vienna. One of his most important achievements was his discovery of the Doppler effect. We see the Doppler effect a lot in our daily lives, but none of us realize the importance of this phenomenon or even thought about it. However, the scientist Doppler was able in the early nineteenth century to explain this phenomenon, which was named after him, on light and sound [1]. The discovery is (the frequencies of sound and light increase or decrease depending on the movement of the source towards or away from the observer). By the late 1830s, trains capable of exceeding 30 miles / hour had begun to penetrate deep into the Austrian countryside. These trains were releasing an acoustic phenomenon that people had not known before, as these trains allowed people to observe the effect of the movement of an object on the sounds emitted from it. Doppler was secretly observing trains passing by and began to analyze the reason for these sound shifts he heard. In 1843, he expanded his thinking to include light waves as well under a general theory that the motion of a body increases or decreases the frequency of the sound and light it emits relative to a stationary observer. He claimed that this shift was the reason for the red and blue tints of the light emitted by distant twin stars. The twin orbiting toward Earth would emit higher-frequency light that shifted toward the blue. The other twin orbiting farther away would emit lower-frequency light that shifted toward the red. [2]

Doppler Effect

The Doppler effect is one of the physical phenomena that can be observed in our daily lives. For example, when a speeding car approaches one of us, provided that he does not change his location, he hears the sound of the engine, which is loud at first as the car approaches him, and then after passing him, the sound increases in intensity as it moves away. It is not accurate to consider the Doppler effect as an effect limited to sound waves only. It applies to other waves such as light, for example. In fact, the Doppler effect has many important applications currently. In order to discuss the Doppler effect in a comprehensive manner, we must first know a brief about waves and their properties. There are two types of waves: longitudinal waves and transverse waves, where the direction of oscillation of the medium is in the same direction as the wave propagation in the first type, while perpendicular to it in the second type. The longitudinal wave is nothing but compressions and rarefactions of a certain medium. If we compress the surface of a certain medium and then let it return free, the molecules of this medium are compressed together in the same direction as the external pressure. This pressure is transmitted in the same direction to the internal molecules in levels parallel to the external compressive surface. The largest example of this type of wave is sound. Air molecules are compressed at the source of the sound and then return to be rarefied [4].

Ultrasound waves

The first studies of ultrasound began in 1826 when the Swiss physicist (Daniel Colladen) tried to calculate the speed of sound using a water bell in Lake Geneva. In 1877, based on the results of this experiment, the scientist (Lord Rayleigh) was able to develop a theory of sound, through which he explained the physical basis of sound waves. And how they are transmitted and reflected. With the continuation of research, a sound radar design was reached in 1914 in the United States of America (sonar)) based on ultrasound waves, which was used for navigation purposes and was also used in World War I to determine the locations of the German Marines. Ultrasound waves were not used for medical purposes until the early 1940s if they were used in medical diagnosis for the first time by the Austrian neurologist (Karl Theodo), but he faced some obstacles due to the absorption of the skull, which blocked the energy of ultrasound waves. Ultrasound devices that operate with specific waves (A-mode) were developed into devices based on ultrasound waves (B-mode), which were distinguished from their predecessors by their high ability to penetrate body tissues. Radiologist Douglas Horry invested this type of waves in diagnosis, as he was able to produce an anatomical image of the body's organs in cooperation with his colleague, scientist Joseph Homles, a kidney specialist, who in turn took over this direction of medical research. In cooperation with scientist Busaconi and engineer Belz, the first two-dimensional ultrasound device (B-mode) was introduced in 1951. Devices that work with this system were developed. However, they were all bulky and required the patient to remain motionless during his partial or complete submersion in water for a long period of time. This made them useless and impossible to use in specialized clinics. At the end of 1955, a movable metal arm was developed that was placed on the area to be examined. Since then, these devices have become more sensitive, smaller, and easier to use in the examination process [3].

Doppler Effect

You may have noticed how the sound of a car changes when the car is moving away from you. The frequency of the sound you hear when the car is approaching you is higher than the frequency you hear when the car is moving away from you. See Figure 1.

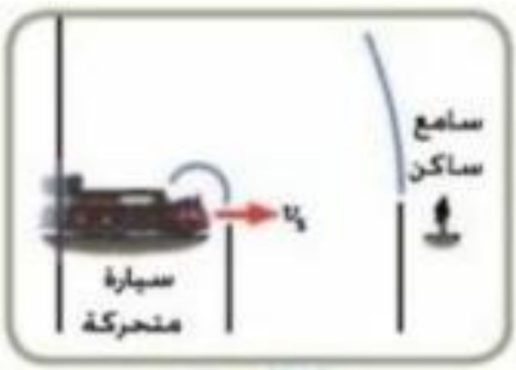

Figure (1): The distance of the car relative to the resident.

The phenomenon of change in the audible frequency from the source frequency if the medium, the listener or the source move relative to each other is called the Doppler effect. The Doppler effect studies the change in the frequency of the audible wave emitted by a sound source in the event of a relative movement between the source and the listener when the medium is stationary or moving. Note Figure (1). To clarify this effect, we assume that the medium is stationary and that the sound source and the listener are in two states of approaching or moving away from each other. An example of this is the sound of a moving train, as the pitch of the whistle increases as it approaches the standing listener and decreases as it moves away from him [5]. If we are dealing with the frequency of sound waves emitted by the movement of a car or an airplane where the speed is much less than the speed of light, then we are talking about the classical Doppler effect. However, if we are dealing with electromagnetic waves that propagate at a speed of equal to the speed of light We are talking about the relativistic Doppler effect.

Doppler Effect Law Mathematically:

Only one vibration equals the reciprocal of the frequency; and it is expressed as As for the second law; it states that there is a correlation between T=1/f: as follows, and the relationship is inverse with the hypothesis L and the wavelength F and the frequency C the speed of propagation of the previous waves; when one of them is large, the value of the other is small, and this law is expressed as follows F=c/L. The Doppler effect is defined as (the change in frequency or wavelength as a result of the movement of the source approaching or moving away from the listener). The Doppler Effect in sound occurs when there is a relative movement between each of:

The source of the sound wave

The medium transmitting the wave

The receiver that receives the wave (the listener)

The Doppler effect in sound is not symmetrical. When the source approaches the listener at a certain speed, the pitch of the sound appears different from the case in which the listener approaches the source at the same speed [6].

Doppler shift:

-1 The sound source and the source are stationary.

When the source moves, its frequency remains constant, but the frequency received by the observer is the one that differs. When the source approaches the observer, the time interval between the arrival of each two successive waves (the period received by the observer decreases), but when the source moves away from the observer, the period increases. Doppler theory is formulated mathematically according to two basic laws; the first law states that the period or time, see Figure 2.

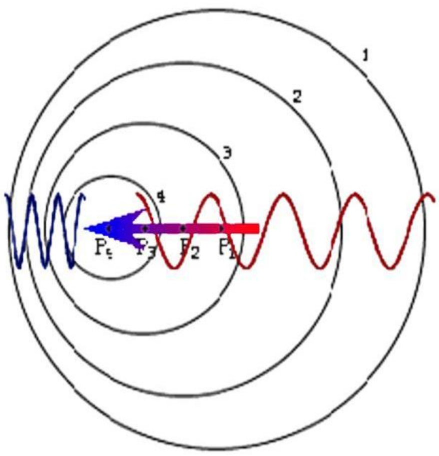

Figure (2): The shape of the wave position during the movement of the source.

When a sound source approaches a listener with a speed Vs emitting a sound of frequency F, during one complete period the source has moved a distance $x=Vs\ T$ and the wavelength reaching the observer is $\Lambda^{\prime}=\Lambda-x=\Lambda-VsT=vT-VsT=T(v-Vs)$

Hence the audible frequency is:

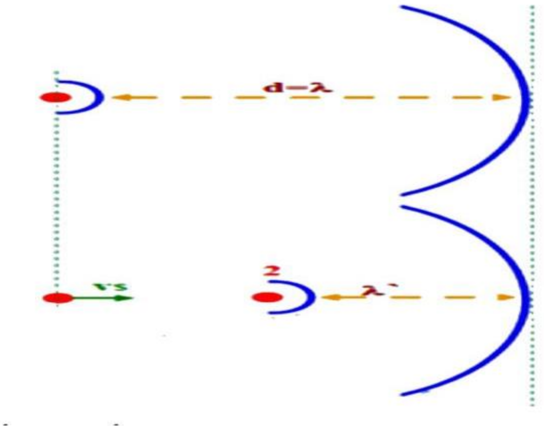

Figure (3): An illustration of the compression of sound and light waves.

$$F'=v'=vV-VSf$$

Where $F=1/T$

In the same way, we conclude that if the source was moving away from the observer, the distance it would travel would be X, but the wavelength would become:

$\Lambda^{\prime}=\Lambda+x=\Lambda+VsT=vT+VsT=T(v+Vs)$

And then its audible frequency would become:

$F^{\prime}=v/\Lambda^{\prime}=v/(V+VS)\ f$

2- The sound source is stationary and the observer is moving:

When the observer is moving, the frequency of the source remains constant, but the frequency received by the observer is the one that differs. When he approaches the car, the observer receives the waves in less time (i.e. the period decreases), but when the observer moves away from the car, the period increases. See Figure (6). If the observer moves with a speed v1 towards a sound source that emits a sound with a frequency f, then the speed of sound received by the observer is $v'=vl+v$ and the observer hear a sound with a wavelength Λ (i.e. the same wavelength of the emitted sound) and its frequency is equal to:

$f'=v'/\Lambda=vl+v/\Lambda=[vl+v/v]\ f$

If the observer moves away from the source, then the speed of sound received by the observer is

$f'=[v-vl/v]\ f$

3- The sound source is moving and the observer is moving:

If the source and the observer are approaching each other, then the speed of sound received by the observer is:

$V'=vl+v$

And the wavelength reaching the observer is:

$\Lambda^{\prime}=T(vl+vs)$

Thus, the frequency received by the observer is [7]:

F'=v'/Λ'=(vl+v/ v-vs)f

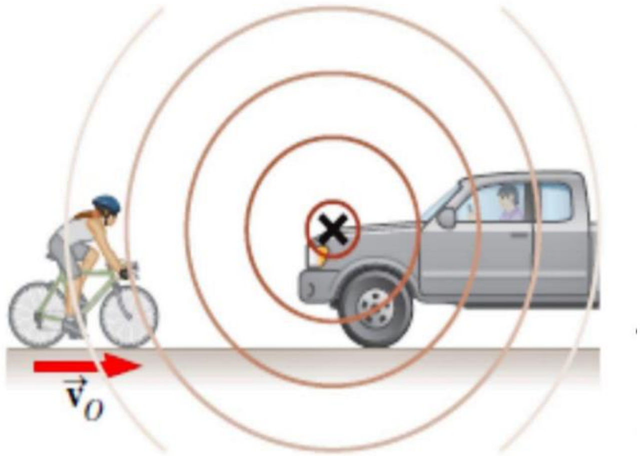

Figure (4): Shows the waves emitted from a stationary car.

Doppler Effect for Light

The resulting Doppler shift in frequency occurs for any waveform. For sound waves, the Doppler shift equations vary significantly depending on whether the source, observer, or air is moving. Light does not require any medium to travel, and the Doppler shift of light traveling in a vacuum depends only on the relative speed of the observer and the source.

Doppler Effect in Astronomy:

The Doppler effect is known as the apparent change in wavelength or frequency of light or sound waves, after an observer or viewer observes it from a fixed point, to facilitate the vision of a near or distant object to determine its location. The first application of this phenomenon became known in 1929 according to the American astronomer "Hubble" with the discovery of many galaxies moving away from Earth at great speed and in different directions; indicating the expansion of the universe is considered one of the greatest human discoveries of the twentieth century.

Measuring the velocity of fluids:

The basic principle of measuring the velocity of fluids is that its velocity at a point is the same as the velocity of a particle of it at that point, since it is very small.

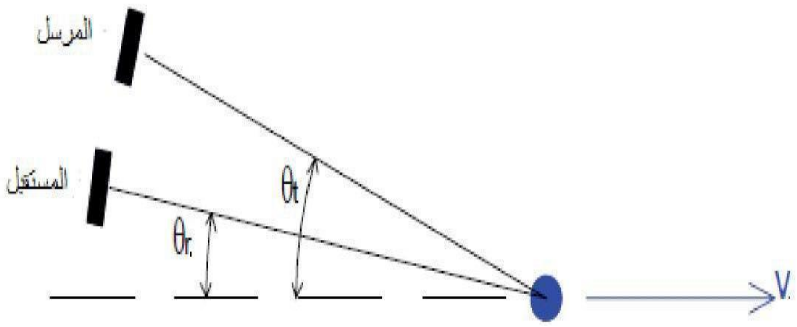

Figure (5) is an illustration of the path of waves in a fluid speed meter.

Liquids using ultrasound waves or using laser beams. The transmitter and receiver are placed so that the angle that each of them makes with the beam of the particle's speed is approximately equal. The transmitter sends the wave towards the particle that is moving quickly, and the particle receives the wave at another frequency as a result of the Doppler shift because the source is stationary and the particle is moving, then the rays are reflected from the particle, so the liquid body becomes like a wave source, and thus the receiver receives the wave at a shifted frequency because the source, which is the particle, is moving and the receiver is stationary. By reading the frequency received by the receiver, the speed of the particle, i.e. the speed of the liquid, can be known by the relationship:

$f' = 2f\, v/c \cos\theta$

Where θ is the angle between the wave and the beam of the liquid speed. Thus, we can measure the speed of liquids based on the Doppler effect, but this method of measurement causes a major problem, which is the light falling on the receiver at a high frequency that may reach the order of It is a big number.

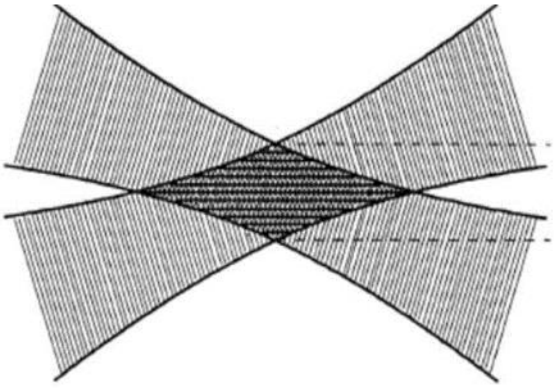

Figure (6) shows the wave interference area.

To avoid this problem, another laser beam is used with the NDF device in place to reflect the wave frequency and direct the second laser beam towards the particle in a way that intersects with the first beam to form an interference area, which is the area in which the fluid velocity can be measured. When the two beams collide with the particle, each one is reflected towards the receiver.

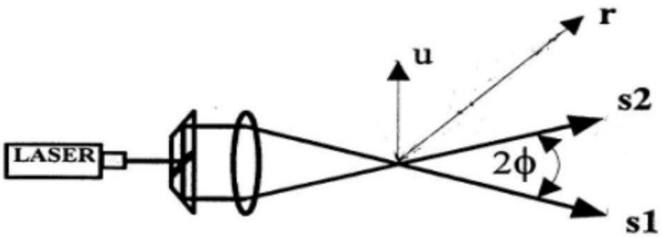

Figure (7) is an illustration of the path of two waves in a fluid speed measuring device.

The benefit of the NDF device lies in reducing the frequency value falling on the receiver to become between (10-100) MHz [11].

Radar:

Radar is an electronic system that uses electromagnetic waves to determine the coordinates of the location of fixed and moving objects in space, as well as their direction and speed if they are moving, and to determine the nature of these objects if possible.

Uses of Radar

Radars are used in countless applications, and their use in many of these applications has improved their performance. In fact, radar failure in them may lead to complete paralysis in their work, as in air and marine navigation systems. The tasks of radars in various applications are limited to four main tasks: surveillance, tracking, radar imaging, and ground penetration to detect what is beneath its surface (ground pentration). In each application, there are countless types of radars, as they vary in their sizes, frequencies used, scanning methods, antenna types, and signal processing methods, which in turn is reflected in their prices, which range from several hundred dollars to millions of dollars.

1. Military uses: The most common areas of use of radar are the armed forces of various types, land, sea and air. Military needs were the main motive for the emergence of radar and its development to the level it is at now. Radar is used in military systems in countless tasks, and the size of the radar ranges from those carried by hand to those occupying hundreds of square meters, while its complexity ranges from those measuring the distance of the target to those drawing three-dimensional images of battlefields. The most important tasks of radar in military systems are to detect and determine the locations of enemy military targets such as warplanes, missiles of various types, aircraft carriers, submarines, ships, warships, tanks, cannons, vehicles and even individuals. The second task is to guide missiles, cannon shells and tanks against enemy targets automatically and hit them with high accuracy by determining the location of the target or by illuminating the target with electromagnetic waves from missiles loaded with radars that capture the wave reflected from the target and direct the missiles towards it. The range of radars used in anti-aircraft guns is ten kilometers, while it reaches thirty kilometers in short-range missiles, one hundred kilometers in medium-range missiles, and thousands of kilometers in long-range missiles.
2. Air navigation radars: Radar has become an important and indispensable tool in air navigation. Its use in airports as well as in aircraft has contributed to the efficient use of airports by increasing the number of arriving and departing aircraft as well as reducing aircraft accidents while flying in the air or during take-off and landing. Air traffic control (ATC) systems use different types of radars, some of which are long-range and some of which are short-range, to track the movement of civil aircraft in the air and guide them during their flight between airports, where the waves reflected from the aircraft appear as bright dots on the radar screen. The flight path of each aircraft can be determined by following the movements of these dots on the screen within a circle whose radius may reach eighty kilometers. Air traffic controllers in control towers use radar screens to direct the continuous flow of arriving and departing aircraft by choosing the most appropriate paths for the aircraft and determining their takeoff and landing times, as well as assisting pilots when landing in bad weather. Modern types of radars called Secondary Surveillance Radar (SSR) can identify the aircraft through a communications system that corresponds with an automatic device carried by the aircraft called a transponder, which provides the airport with the necessary information about the aircraft. The Precision approach radar (PAR) helps the control tower to land aircraft safely on The airport runway, especially in bad conditions. Most modern aircraft have different types of radars that help the pilot during flight, takeoff and landing. For example, a radar altimeter is used to determine the height of the aircraft above the ground, especially during takeoff and landing. Aircraft also have radars placed in the front of the aircraft to know the weather conditions on the aircraft's path, to help the pilot avoid bad conditions and make appropriate decisions when landing.
3. Marine navigation radars: Radar is widely used in various types of ships, oil tankers, warships and aircraft carriers, as radar determines the locations of other ships at sea, as well as the locations of beaches, small islands, rocks and snowy mountains that obstruct the path, thus avoiding collision with them. In ports, radar is used to detect the presence of ships and determine their distance in the waters surrounding the port in order to regulate their entry and exit from the port. The design of marine navigation radars is much more difficult than those in air navigation because the target is close to the surface of the water and at relatively low altitudes, and the target gradually begins to disappear from the radar's view due to the curvature of the earth. Usually, radars with relatively low frequencies of less than one gigahertz are used to reduce the absorption of waves by the water that spread close to its surface. The maximum range of these radars does not exceed one hundred kilometers due to the curvature of the earth, as we mentioned, and the radar is usually placed on high towers to increase its range of vision.

4. Weather Radars: Radars are used to help meteorologists know and predict weather conditions. Radars detect the presence of clouds, rain, snow, storms and hurricanes of various types and map them on radar screens. Meteorologists extract a lot of information about the weather conditions in terms of cloud density, rain and snow they carry, their heights, sizes and direction of movement, as well as the intensity of rain and snowfall. Certain types of radar are used to determine the speed and direction of winds in different layers of the atmosphere. Pulse type weather radars are used, where the intensity of the reflected pulse is directly proportional to the density of clouds, rain, snow and sand, and their speed of movement can be determined using the Doppler effect. The frequency on which the weather radar operates must be carefully selected and within a specific range, which is between three and thirty gigahertz, because the intensity of the reflected pulse depends on the length of the transmitted wave compared to the sizes of raindrops, hailstones and pieces of ice. The transmitted wave capacities of weather radars range between 100 watts and 50 kilowatts depending on the type of radar and the range it covers. Modern weather radars use image processing systems to obtain accurate images of weather conditions. Airports and ports use short-range radars with a range not exceeding 100 kilometers to know the weather conditions around them in order to guide aircraft and ships and give appropriate advice to pilots and captains when entering their airspace.

Remote sensing

Satellite and aircraft-borne radars are used to study the Earth's surface and its components by sending electromagnetic pulses at specific frequencies and then capturing the pulses reflected from the Earth's surface and analyzing them using digital signal processors to draw images of the scanned area. These images are used to extract important information about the nature of the land scanned by the radar beam, including the nature of the terrain and its topography, the type of forests, plants, cultivated crops, agricultural pests, climatic and environmental conditions, volcanoes, hurricanes, floods, mineral resources, groundwater, and oil. There are different types of remote sensing radars that are designed based on the type of information to be sensed, and this often depends on the frequency used in the radar. Searching for Earth's resources requires the use of frequencies of less than one gigahertz due to their ability to penetrate the Earth's surface, while drawing a topographic map requires frequencies much higher than that to obtain a high ability to distinguish the Earth's terrain (12).

Doppler Ultrasound Devices:

This type of device relies on the Doppler phenomenon as is clear from its name, where the speed of blood flowing from the heart to the arteries and blood vessels can be measured by calculating the frequency difference between the incident and reflected waves, as the incident waves change their frequency when reflected from moving parts. Medical ultrasound is divided into two distinct categories:

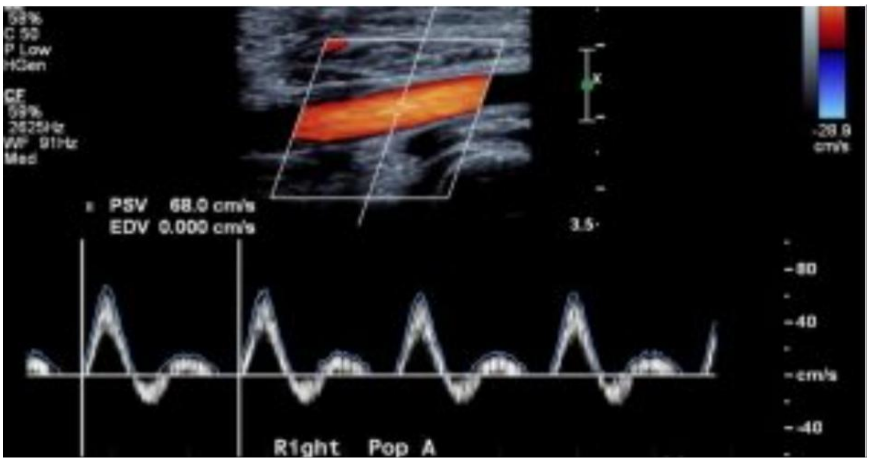

Image (8). Doppler of blood vessels.

1. Diagnostic ultrasound:

It is a non-invasive diagnostic technique used to image the inside of the body. Ultrasound probes, called transducers, produce waves with frequencies higher than 20 kilohertz, but most transducers in use today operate at much higher frequencies (in the megahertz range). Diagnostic ultrasound probes are placed on the skin. However, to improve image quality, the probes can be placed inside the body through the digestive tract, vagina, or blood vessels. In addition, ultrasound is sometimes used during surgery by placing a sterile probe in the area being operated on. Diagnostic ultrasound can also be divided into anatomical and functional ultrasound. Anatomical ultrasound produces images of internal organs or other structures. Functional ultrasound collects information such as blood movement and speed, the softness or firmness of tissue, and other physical properties. By combining both types, "information maps" can be created. They help doctors visualize changes or differences in function within a structure or organ.

2. Therapeutic ultrasound:

This type of waves does not produce an image and its purpose is to interact with tissues in the body so that they are modified or destroyed. Possible modifications include: moving or pushing tissues, heating tissues, dissolving blood clots, and delivering drugs to specific areas of the body. Destruction and ablation operations have become possible through the use of high-intensity beams that can destroy diseased or abnormal tissues such as tumors. The advantage of using ultrasound therapy is that in most cases it is non-surgical, without the need to make incisions in the skin, i.e. without leaving wounds or scars. Ultrasound is used to diagnose many diseases, including:

- Diagnosing hyperthyroidism or hypothyroidism.
- Detecting liver tumors by determining size and shape.
- Determining the causes of stroke by diagnosing arterial blockages, as the device provides a quick means of diagnosis in such cases compared to other methods.
- Diagnosing cases of back or spine problems through spinal cord imaging.
- It is used to monitor pregnancy through fetal imaging to ensure the safety of the fetus as well as to diagnose some abnormal conditions such as physical deformities in the fetus.
- Diagnosis of prostate tumors in men.
- Diagnosis of uterine and ovarian fibroids and to determine the presence of uterine cysts in women.
- It is also used to direct the needle to the correct location in case a biopsy is needed.
- Therapeutic uses of ultrasound include the following:
- Breaking up large kidney stones and gallstones.
- Excision (removal) of uterine fibroids, or non-cancerous growths in the uterus.
- Teeth cleaning.
- Removing eye cloudiness.
- Physical therapy (heating tendons, muscles and other tissues) for conditions such as tendonitis.
- Treatment of tumors and cysts.
- Stimulating bone growth to heal fractures.
- Opening tissues with surgical operations as well as stopping blood flow.
- Helps in directing drug delivery to specific tissues. Benefits vs. Risks: Most ultrasound examinations are uncomfortable but painless because they do not require surgical intervention (needles or injections). Ultrasound is widely used and less expensive compared to other

imaging methods, in addition to being very safe and does not expose patients to any ionizing radiation like other imaging methods. Soft tissues can be clearly shown on ultrasound examinations that are not well shown by X-ray examinations, and ultrasound examinations are the best method for monitoring and diagnosis during pregnancy. The real-time imaging feature provided by ultrasound makes it a useful tool for minimally invasive medical techniques such as fluid aspiration and needle biopsy. Although no pathological cases have been recorded with ultrasound examination so far, it is recommended to use it only when necessary to avoid exposing parts of the human body to the high energy generated by ultrasound waves, which are easily absorbed by water in living tissues, leading to an increase in the local temperature in the area exposed to ultrasound. Studies have also indicated that women who use ultrasound in physical therapy are more susceptible to premature birth or miscarriage. It is worth noting that some studies indicate that prolonged exposure to ultrasound may have biological effects at the cellular level within the human body (3).

Doppler effect in medicine

Detection of clots: In healthy blood vessels, blood moves in a layered manner, meaning that red blood cells move at the same speed in the form of parallel bundles and in the same direction, but due to the friction of the blood with the walls of the blood vessels, the cells adjacent to the wall move at a slower speed. However, if there is an obstacle in the blood vessel, the flow becomes forced flow, in which the cells move at different speeds and in different directions, and the speed of the blood is greater. By using the echo, it is possible to identify the areas that contain obstacles.

Echo: It is a device that emits ultrasonic waves through the body, and these waves result from a rapid vibration of the type of crystal that gives ultrasonic frequencies that send the waves, and their echo is received by a piece called a probe. This probe must be in close contact with the skin, and the skin is smeared with a gelatinous liquid in the area being studied so that the ultrasonic waves can burn the skin. Fixed tissues reflect these waves and reach the receiver at the same frequency. However, when the waves fall on moving particles, they reach the receiver at another frequency, i.e. they are subjected to Doppler shift. By directing the echo on a blood vessel, for example, the frequency can be calculated, and through this frequency the speed of the blood in the tube can be known through the relationship we mentioned previously: $F=2f\text{-}\cos\theta$

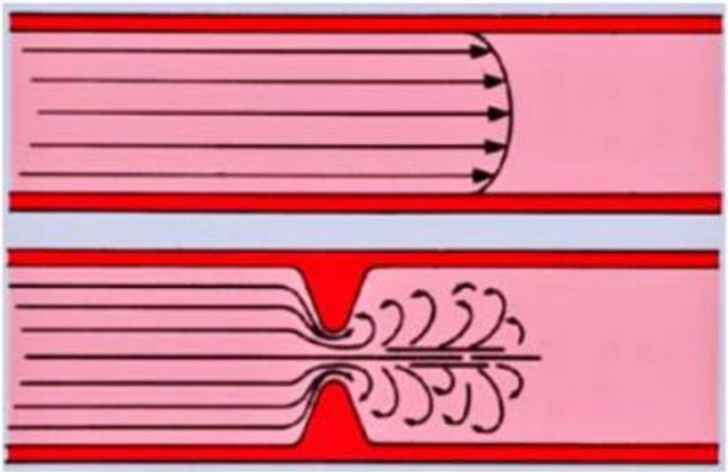

Image (9) Blood movement disorder caused by an obstruction in the blood vessel.

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