Doppler sonography (2. LF UK)

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Introduction

Doppler sonography (also known as ultrasonography) fits into the general diagnostic non-invasive medical imaging methods. It is used for assessing the velocity of blood flow in arteries. It is also know as Doppler ultrasound (DUS). This article will talk about the theoretical principles of Doppler sonography and on the procedure to be followed during biophysical practicals at the second faculty.

Literature review

Doppler sonography is a modern, painless and today easily accessible diagnostical method. The inventor of this method was an Austrian mathematician, professor Christian Doppler (1803-1853). It is used daily to examine the blood vessels of the neck, the limbs and organs (for example, diagnosing varicose veins, thrombosis, arterial blockages in upper and lower limbs, and blood vessels mainly in the brain) but also in childbirth and neonatal medicine. Doctors consider Doppler sonography as a big step forward in the diagnosis of vascular diseases. There is still an open question, whether the method is completely safe especially during pregnancy.

The advantage of this procedure is that the diagnosis doesn't require the use of ionizing radiation. Another advantage is the price of the diagnosis, which is much less than that of the diagnosis using comparable imaging methods, and also its wide usage.

The disadvantage of the method is seen in low penetrability through areas with different acoustic impedances (eg subcutaneous fat, gas or pulmonary parenchyma).

Ultrasound is a type of mechanical wave with a frequency higher than 16 kHz, which is inaudible to the human ear.

Doppler effect

The Doppler effect is highlighted by noting the change in the frequency of the siren of an ambulance that is approaching and then moving away from us. The Doppler phenomenon involves change of frequency of the received sound when compared to the transmitted frequency. The reason behind it is the non-zero relative speed of the transmitter and the receiver (the ear of the observer in this case). When the vehicle is approaching, we perceive the sound as of higher frequency, if it is moving away from us we perceive the sound as a lower frequency.

This phenomenon is not only found in ultrasound waves but also in radar waves in speed cameras or light emitted by moving galaxies. The spectrum of the receding stars will be shifted toward the red color. Using the Doppler effect, the speed of a moving interface, such as a heart valve, can be easily measured and monitored.

During Doppler sonography, ultrasound waves are reflected by moving structures in flowing blood- erythrocytes. The difference between the transmitted frequency of the ultrasound transducer and the received reflected frequency is called the Doppler frequency shift (Δf).

In **Continuous Doppler Imaging** separate transmitters and ultrasonic receivers are used whilst **Pulsed Doppler Imaging** pulses are used to obtain also positional information (as the usual ultrasound imaging).

Doppler effect in medicine

The primary reflection structures in the flowing blood are erythrocytes. Since their magnitude is substantially smaller than the wavelength of the incident ultrasound waves, the erythrocytes act as scatter point sources, which give rise to circular wavefronts propagating in all directions. These waves interfere with each other and their temporal and spatial summation occurs. For the formation of the doppler signal, the part of the ultrasound wave energy that is reflected back to the transducer is the important factor. The amplitude of the reflected wave is proportional to the second power of the total number of erythrocytes. If the blood flows towards the transducer, then the frequency of the reflected wave is higher than the transmitted frequency, if the blood flows away from the transducer, the frequency is lower.

The actual blood flow rate can be calculated from the Doppler frequency shift Δf and the Doppler angle that is the angle between the Doppler beam direction and the direction of velocity of the moving blood. We actually do not measure velocity but only the velocity component in the direction to the probe or from the probe. Therefore, if the blood flow measuring probe is located perpendicular to the vessel, it measures zero speed. Underestimating the significance of the Doppler angle may lead to significant errors in the measurement of speeds particularly at angles greater than 60 °.

Doppler sonography is used for other examinations, for example: to detect silent bubbles that may be a symptom of a decompression illness resulting from poor procedures during diving. **Doppler systems**

Doppler devices

Blood vessels pose a certain mechanical resistance to the flow of blood. Peripheral blood vessel vascular resistance is inversely proportional to the 4th radius of the vessel. The cross-section of the vessel determines not only the magnitude of the peripheral resistance, but also the character of the blood flow. If the velocity at a narrow point in a blood vessel exceeds a certain critical value, the laminar flow changes into turbulent. In a color Doppler image, the turbulent flow shows up as a mosaic of pixels of different colors. In the vascular system blood flow is pulsating. During systole, acceleration of the flow occurs and a maximum speed achieved, during diastole there is a deceleration with a minimum speed at the end of the diastole. Continuous pulse flow is maintained due to the elastic properties of the aorta and some other large vessels. These arteries constitute a blood reservoir and, due to the elasticity of their walls, they temporarily transform part of the kinetic energy flowing through the systole into their elastic tension, and in diastole this energy returns again to the blood. Another factor influencing the pulsating nature of blood flow is peripheral vascular resistance. Accordingly, we distinguish between low-resistance curves (arteries supplying the brain and parenchymatous organs) and high-resistance (arteries supplying skeletal muscles).

Spectral Doppler curve is a measure of the spread of velocities in the blood, the higher the turbulence the higher the spread of velocities. For the assessment of hemodynamic changes, it is necessary to determine some parameters of the blood flow. These include the maximum systolic velocity S, the minimum diastolic velocity D, the S / D ratio (systolic/diastolic ratio), the acceleration index AI , the acceleration time AT, the PI (pulsatility index) and the resistance index RI (resistivity index, resistance index). These parameters have a large diagnostic value, provided the measurement is accurate enough. Very important is the correct setting of the so-called Doppler angle. **Definitions of some parameters**

Definitions of some parameters

Maximum systolic velocity S- maximum velocity in systole. Most of the time it corresponds to the early systolic peak (ESP)

Minimum diastolic velocity S-m(telediastolic velocity)- velocity of the flow at the end of diastole

Mean velocity Vmean- instantaneous or timed. Determination of the instantaneous value is mostly based on the Doppler spectrum analysis - the velocities are weighted by the amplitude echoes, which are determined by the number of red blood cells involved in the generation of echoes. The average rate over time is then an average of instantaneous velocity over a period of time, usually at least one heart cycle.

S/D ratio(systolic / diastolic ratio) - ratio of maximum systolic velocity S and flow rate at the end of diastole D.

Resistive index RI (resistance index)- difference of maximum systolic velocity S and flow rate at the end of diastole D, divided by maximum systolic velocity S. Increasing the peripheral resistance leads to a reduction of the diastolic velocity and the value of the resistance index increases. The resistance index may provide information on peripheral resistance even in parts of the river basin being investigated which are not accessible to direct observation.

Pulse index PI (pulsatility index),pulse index - difference of maximum systolic velocity S and flow rate at the end of diastole D, divided by average velocity (Vmean); expresses the energy of pulsating blood. It has somewhat different values for individual arteries and its diagnostic significance is not yet fully appreciated.

Heart rate HR (heart rate) is the number of heart rate per unit time, most often per minute. HR = 1 / T where T is the length of the heart period.

Systolic acceleration is characterized by a change in the rate of blood flow at a given artery site from

the onset of the systole to achieve a systolic peak. It is expressed either as the acceleration index (AI), which characterizes the line slope from the onset of the early systole to the systolic peak, or the acceleration time (AT), the time between the systole's start and the systolic peak.

Imaging modes

In general, doppler measurements can be performed in two modes.

Continuous Wave CW Doppler: This means that the transducer transmits a continuous wave. A transducer with two halves is used, one of which functions permanently as a transmitter, the other as a receiver. **Doppler Flowmeters** use this system and are equipped with an acoustic output for the Doppler frequency shift. The devices are simple and affordable, but you cannot view the layout and location of the vessels being monitored, their overlaps, etc. The method is mainly used to monitor the flow of blood in the limbs.

Pulsed Doppler PW: The transducer transmits ultrasound in pulses. By measuring the time that the reflected pulse takes to return to the transducer one can know the position of the vessel. These devices produce direction lines to show the direction of the ultrasound wave propagation as well as to indicate the direction of blood flow; in this way the device automatically allows for the Doppler angle. It is also possible to define the volume in which the velocity is measured - the 'sampling volume'. A narrow sample volume, located in the center of the artery, measures the maximum speed. A wide sample volume which includes the entire vessel diameter gives the average speed. Doppler measurement in PW mode is possible on most commonly used devices, the result is displayed as a two-dimensional image of measured speeds. The advantage of this method is the possibility of measuring the speed parameters at a chosen depth.

The Medical Device

- Doppler ultrasonic measuring device: **Bidop Hadeco (ES-100V3)**

- Probe & probe cable

- Ultrasound exam gel

- PC (https://en.m.wikipedia.org/wiki/Personal_computer) software: **Smart-V-Link 4.1** & **Gimp 8.2**

Imaging Protocol

During this practical, you will be working with the Bidop Hadeco (ES-100V3) portable doppler ultrasonic measuring device.

Detail presentation. Doppler sonography presentation instructions

Information for Automatic and Manually Measured Values

Measured Pulse Wave Parameters:

- **HR** (*Heart Rate (https://en.m.wikipedia.org/wiki/Heart_rate)*)
- **RI** (*Resistance Index (https://en.m.wikipedia.org/wiki/Arterial_resistivity_index)*)
- **SD** (*Systolic / Diastolic ratio* = S / D ratio)
- **MEAN** (*Mean Flow (https://en.m.wikipedia.org/wiki/Mean_flow)* = average velocity [V_{mean}])
- **PI** (*Pulsatility Index (https://en.m.wikipedia.org/wiki/Hemodynamics)* = pulse index)

Important Notes for the Protocol

- Do not use this device on the chest, abdomen, head, or neck area.
- To prevent any unwanted reflection of ultrasound waves, apply a layer of gel to the contact tip of the probe about 3 mm thick. Once the gel begins to dry, apply a new layer. However, if the gel covers too much dermal surface area, the probe may not record properly.

- While using the probe, carefully and patiently locate the signal. The place for examination is chosen in advance, for example, at a place where you can feel the pulse with the fingers.
- Do not move the probe after finding the appropriate probe location (unlike conventional sonography (https://en.m.wikipedia.org/wiki/Medical_ultrasound)).
- The program may unexpectedly stop (program not responding). Typically, you can resolve the issue by restarting the program without further problems.

Protocol Preparation

- To prepare for the protocol, use the form found under **Doppler Practical** on Moodle. Just before the start of taking measurements, fill in the boxes noting the order of the examiner and patient, the team number, the date, the start time of the examination, the investigated artery, and the investigated side (i.e.- *sin* means left, *dx* right). At the end of the experiment, record the end-time of the examination.
- Write down the measured values from the experiment straight into the data table.
- In the discussion, compare your calculated values with the automatically calculated and any theoretical assumptions you had about your measurements. Also, mention the fact that affects the outcome of the examination.
- In the conclusion, briefly state whether the result of your measurement corresponds to a normal finding and whether a low-resolution or high-resolution curve was measured.

Conclusion

Over the course of the last half decade the development on the field of diagnostic ultrasound has been rapid, the newest technology being 3D-imaging.

The development has not come to an end; new techniques for volume blood flow estimation have emerged. Based on Gauss's theorem, an angle-independent measurement is now possible; the theorem is based on the relation of the integrated flux of a vector field through a surface, and the divergence of the vector field in the closed surface, i.e the inside of the surface.

Doppler sonography improves diagnosis by providing immediate clinical information through imaging, hence the reduction of wrong diagnosis and a reduction of harm to the patient which could be caused by wrong treatments. On the financial side the immediate result reduces overall healthcare costs.

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