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Foundamentals and Applications of Abdominal Doppler

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1. Introduction

Since the Doppler effect was firstly described by Christian Doppler in 1842, it has been applied in many different fields. In human medicine has been extremely helpful in monitoring the fetal viability or assessing the carotid flow, and it is currently being used in most of the disciplines.

In veterinary medicine, the Doppler effect is a helpful tool in abdominal ultrasound, and essential in the echocardiography exam. Its principle can be defined as the apparent shift in transmitted frequency, reflected back to the source off a target, which occurs as a result of the movement of this target. When this effect is applied in ultrasonography, the red blood cells (RBC's) are the moving targets, and the apparent shift in the frequency of the sound reflected back to the transducer is proportional to their velocity and direction of the movement. The software of the ultrasound machine displays this values in a color code (Color Doppler) or in a graphic, (spectral trace of the Pulsed wave Doppler (PW) or Continuous wave Doppler (CW)).

In Color Doppler, a given color is usually assigned to the direction of flow; red is flow toward, and blue is flow away from the transducer (Figure 1).

The center of the color bar, displayed in the screen, is black and represents zero flow. In addition to simple direction, velocity information is also displayed. Progressively increasing velocities are encoded in varying ranges of either red or blue. The more dull the hue, the slower the velocity. The brighter the hue, the faster the relative velocity. Color Doppler is also used to display turbulent flow (showing a mosaic of many colors) and allows an operator to discriminate between normal and abnormal flow states. Color Doppler is useful for assessing relatively big areas, whilst PW (Pulsed Wave) and CW (Continous Wave) Doppler are used for assessing smaller areas of interest. Since Color Doppler is a type of pulsed wave Doppler, it suffers from the same limitations.

Before explaining the difference between CW and PW, explaining the concept of spectral trace is required. This is the graphic representation of velocity flow profile against time. Depending of the number of cells crossing the amount of signal increases (Figure 2).

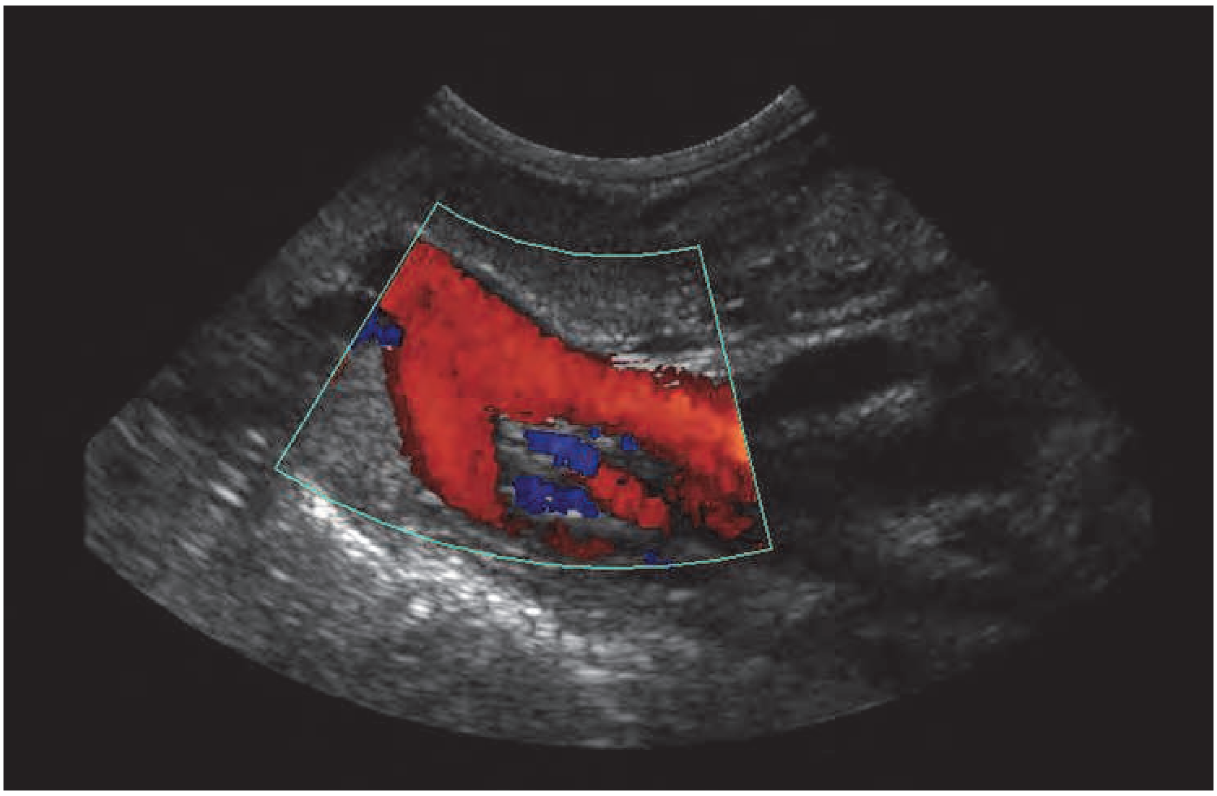

Fig. 1. Color Doppler window depicting the mesenteric veins.

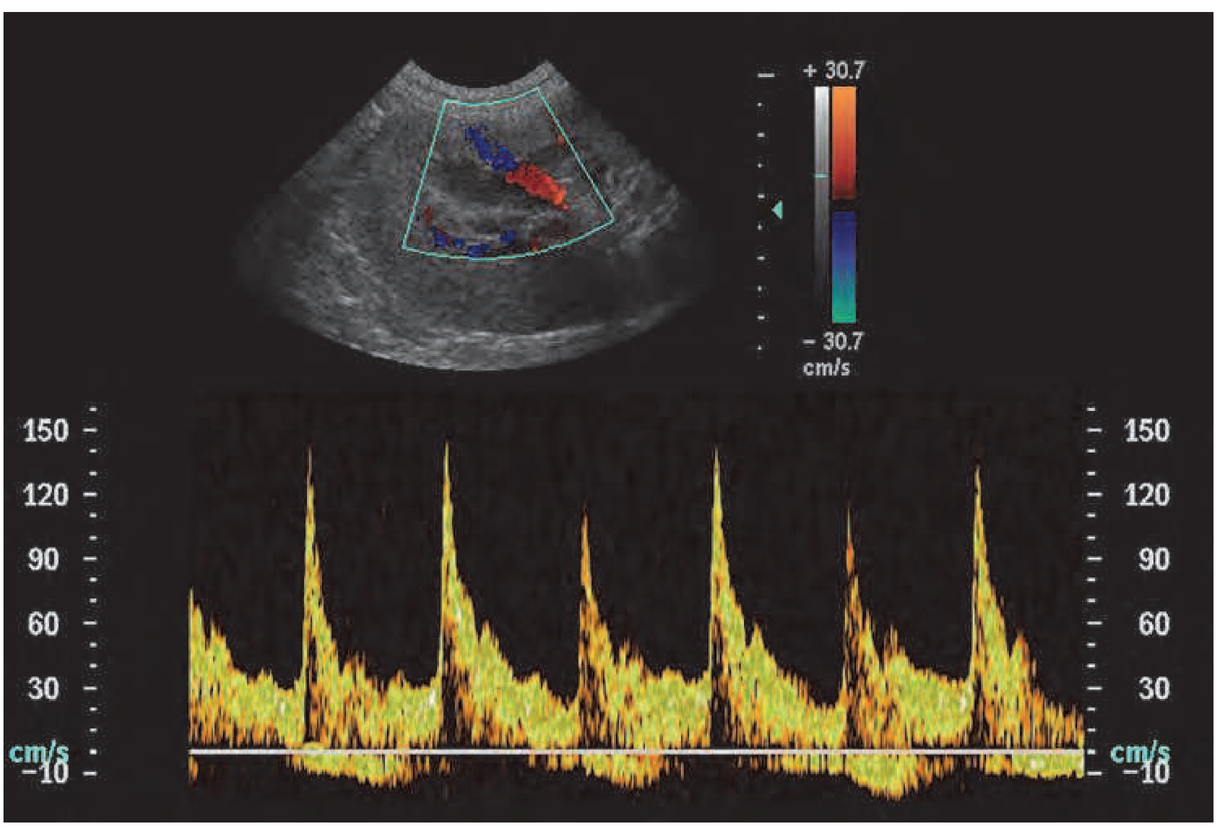

Fig. 2. Spectral trace of an interlobar artery in a kidney

The CW Doppler, is an older technology in which the ultrasound waves are continuously emitted from, and received back by the same transducer so very high velocities can be measured (Figure 3). PW Doppler systems uses only one transducer that alternates packed transmission and reception of ultrasound. The main advantage of PW Doppler compared with CW Doppler, is its ability to provide Doppler shift data selectively from a small segment along the ultrasound beam, referred to as the "sample volume", which it can be controlled by the operator (Figure 4). An ultrasound pulse is sent into the tissues travels for a given time and reflected back by a moving red cell. This ultrasound pulse returns to the transducer over the same time interval but at a shifted frequency. The location of the sample volume it is very important because the speed of ultrasound in the tissues does not change and the roundtrip travel time will differ. In this dependence on the location of the window lies the main disadvantage of PW Doppler, since it will not be possible to accurately measure high blood flow velocities, such as may be encountered in certain types of valvular and congenital heart diseases. This limitation is technically known as "aliasing" and results in an inability to record velocities above 1.5 to 2 m/sec, depending on the depth (Figures 5, 6). Although this artefact is very important in echocardiography, it will be rarely found in abdominal ultrasound, since the velocity of the blood flow in the abdominal vessels is usually lower than 1m/s.

Another main advantage of PW Doppler is the fact that some imaging may be carried on alternately with the Doppler and thus the sample volume may be shown on the actual two-dimensional display for guidance.

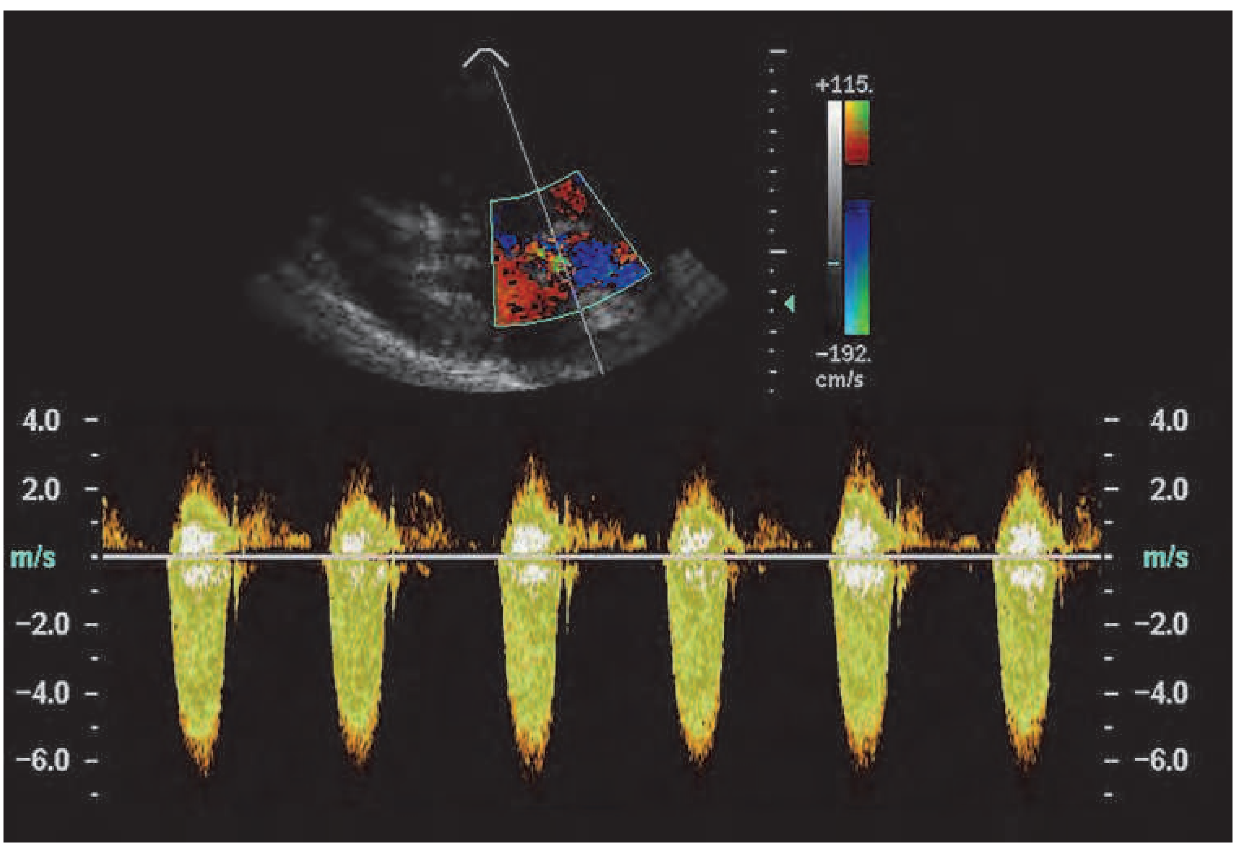

Fig. 3. Continous wave Doppler in a severe aortic stenosis. A high velocity profile (6m/s) is depicted.

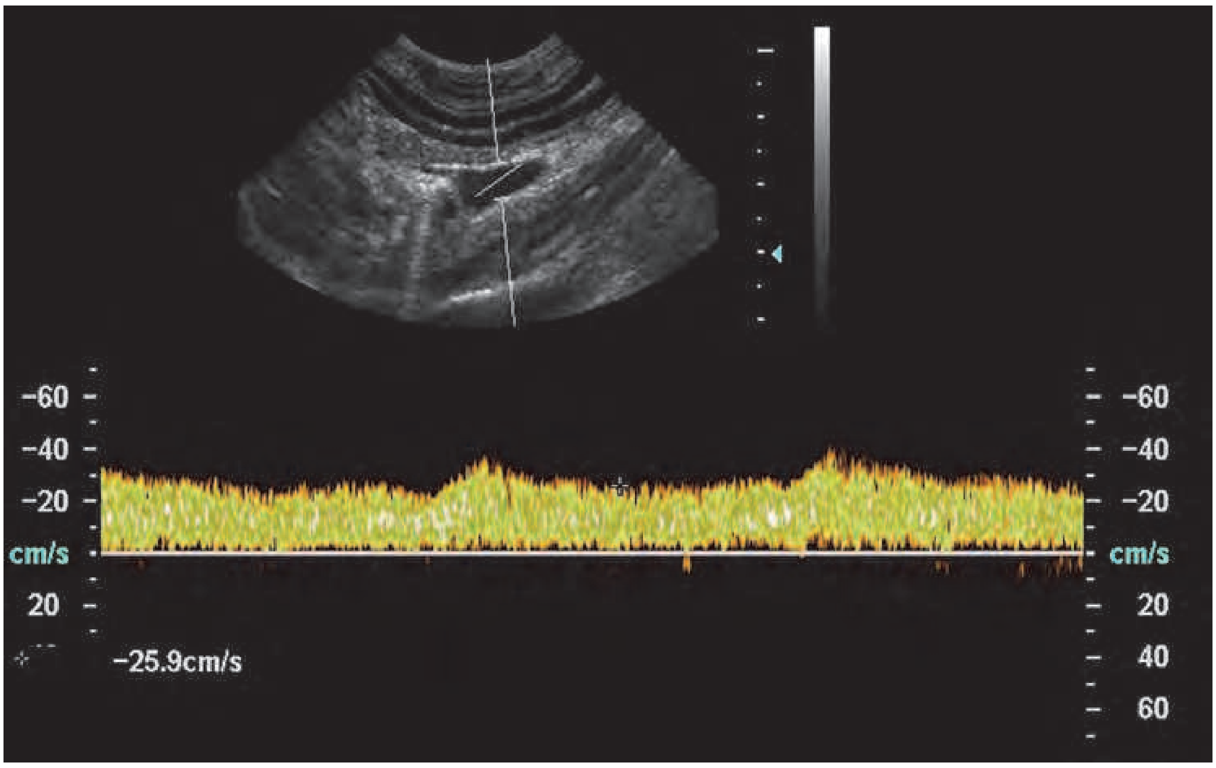

Fig. 4. Pulsed wave Doppler in a normal portal vein. Using the sample volume the sonographer is able to define the studied volume, in this case it has a width of 4 mm.

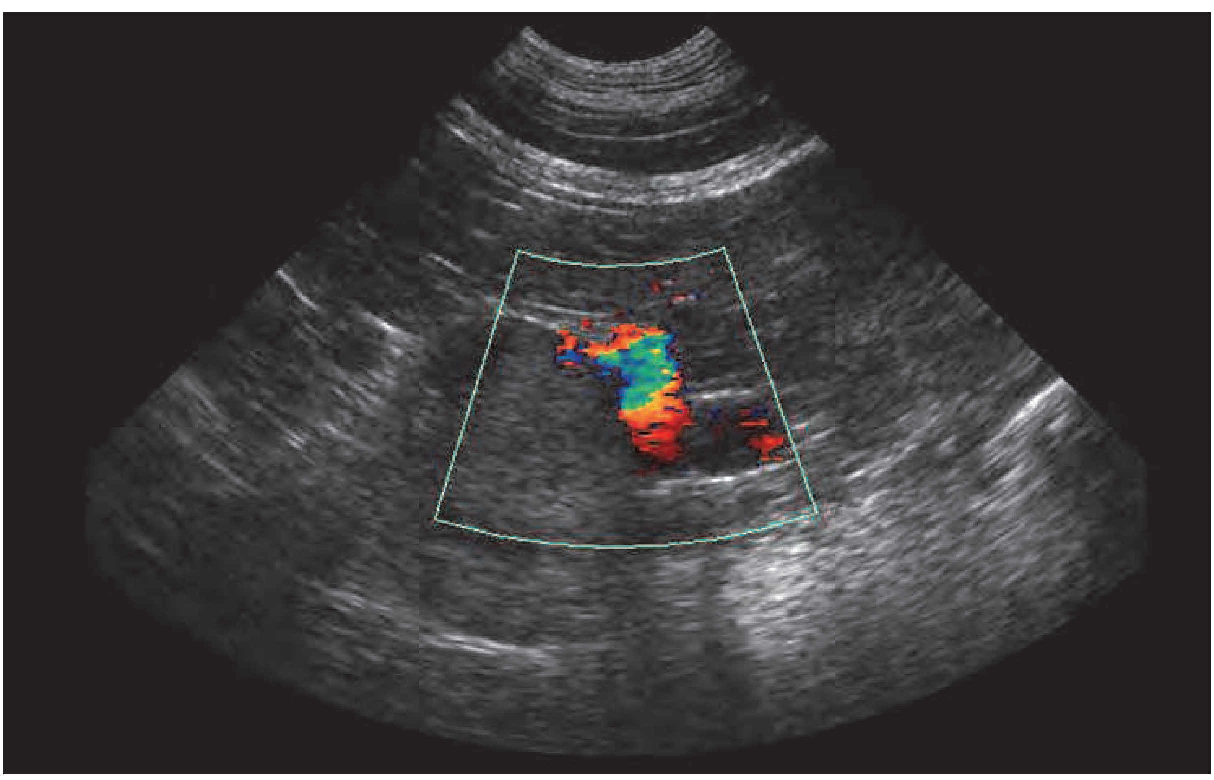

Fig. 5. Aliasing. The velocity overwhelms the máximum limit in the velocity profile (red-yellow), depicting the botom of the negative velocities (green-blue). However the blood dierction does not change.

The spectral trace from PW and CW are also different. When there is no turbulence in the blood flow analized, PW will generally display a laminar (narrow band) spectral trace. However CW rarely displays such a narrow band of flow velocities, because all the various velocities encountered by the ultrasound beams are detected by CW.
PW is usually used when a specific area of abnormal flow is located. Then, If it is important to know the accurate measurement of elevated flow velocity, CW Doppler should be used.

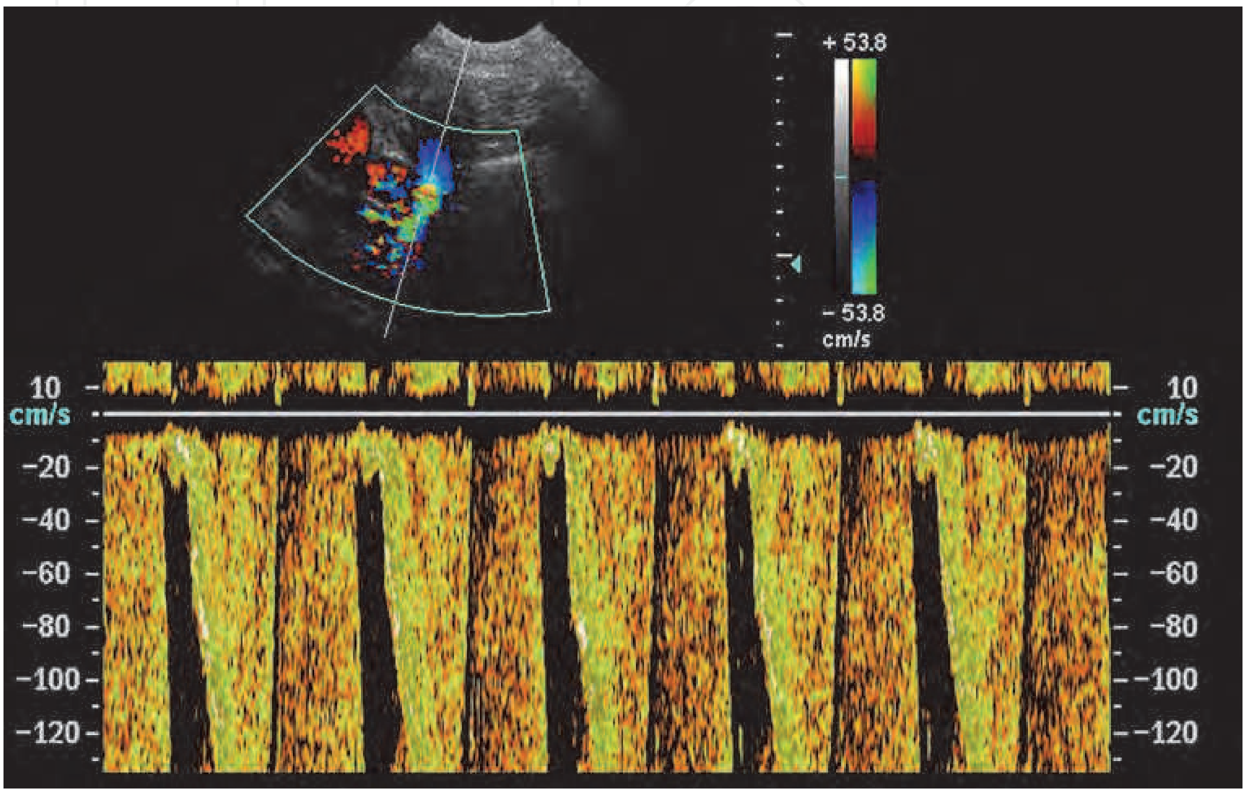

Fig. 6. Non-optimised spectral trace obtained by means of pulsed Doppler. The PRF (pulsed repetition frequency) is to low.

A relatively easy and systematic way to achieve a good spectral trace of a vessel can be summarised as follows:

1. Location of the vessel or area to scan by B mode.
2. Obtain a good view from the area. If the grey scale is not adequate, the Doppler signal will not be optimal.
3. Activate Color Doppler. Unlike in echocardiography, in abdominal ultrasound is preffered to use a higher permanence to be able to identify small structures. The PRF scale should be the adequate to fill up the vessels, being used a combination of high gain and low PRF.
4. Activate PW Doppler. Volume sample should be adjusted to the size of the vessel (usually between 2 and 4 mm).
5. Adjust the angle of insonation. It is convenient to remember that the angle of the probe related to the direction of the vessel will change the values of velocity registered. Refering the reader to the literature provided at the end of this chapter, physics of the Doppler effect will not be explained in depth, but angles between 0 and 60 degrees are recommended to register a reliable velocity.

6. Optimization of the spectral trace. In most of the ultrasound machines, the size of the screen adapts automatically. Changes in the baseline and scale of the velocity will be necessary to obtain the best image.

2. Aplications of Doppler in abdominal ultrasound

The most straightforward application using Doppler in abdominal ultrasound is assessing, by color Doppler the presence or lack of blood flow in a vascularised structures. It is an essential imperative to have a profound knowledge of the machine as well as to set up the settings properly. With this, it can be relatively easy differenciate for example between an haematoma from another lesion, or identify a thrombosis in a vessel wherein can be difficult with the bidimensional mode (Figure 7).

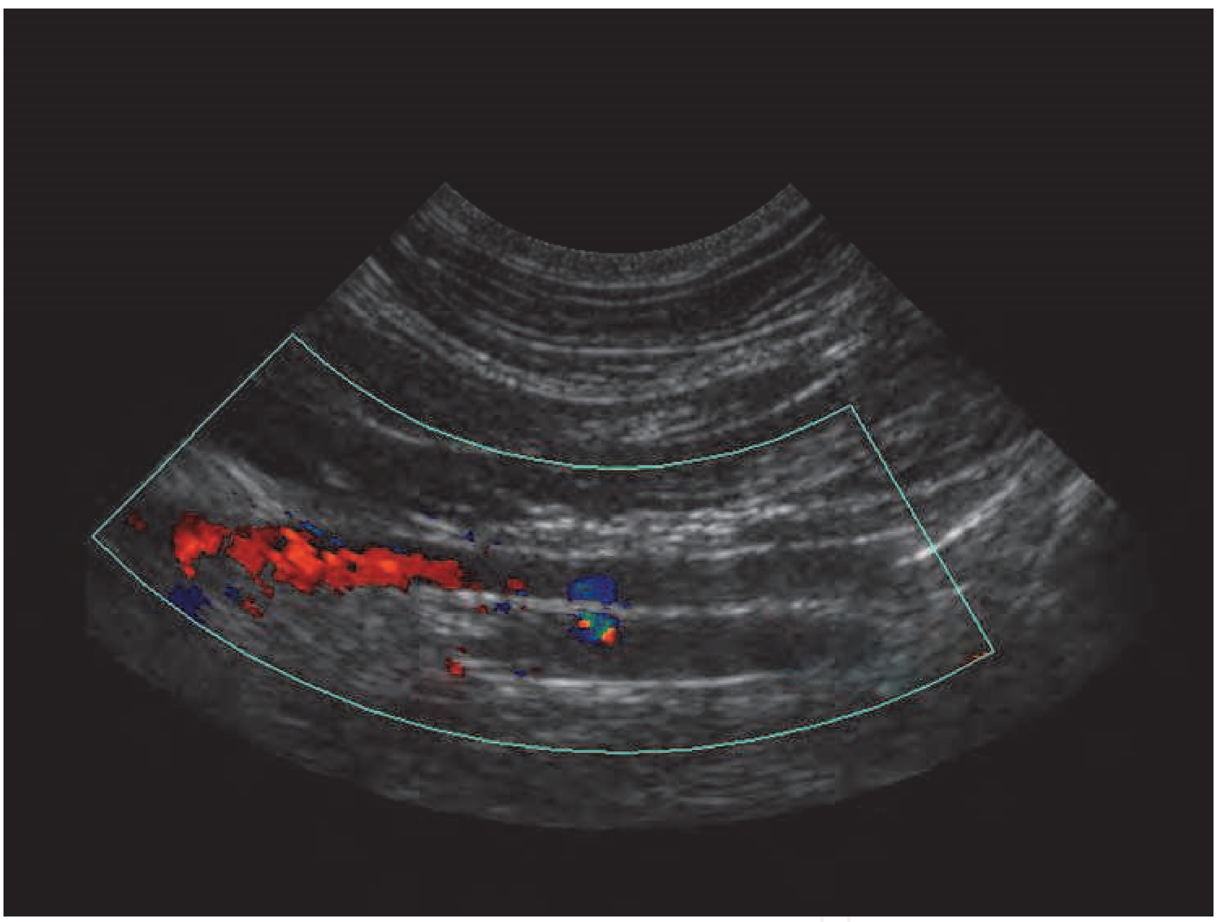

Fig. 7. Trombus in the medial iliac artery. The blood flow is interrupted.

It may also be useful when is necessary localise areas less vascularised to perform aspirations or biopsies. However, when the PRF scale is set up too low in order to improving the identification of small vessels flowing at less than 10cm/s, movements or the breathing can produce artefacts in the window making difficult the interpretation. Other tools, like the Power Doppler (Figure 8), vascular Doppler or B-Flow (currently included in most of the machines), can be very helpful due to its high sensitivity, although they are still affected by the same artefacts. The study of the spectral display of the great abdominal vessels is widely reported in the veterinary literature. Each artery and vein have distinctive trace depending on the vascular beed they supply or areas they connect. As a example, it is totally different the trace of the caudal vena cava, influenced by the respiration and the pressure in the right atrium, than the portal vein, much more stable, due to the similar pressures between the areas connected by this vessel (Figure 9).

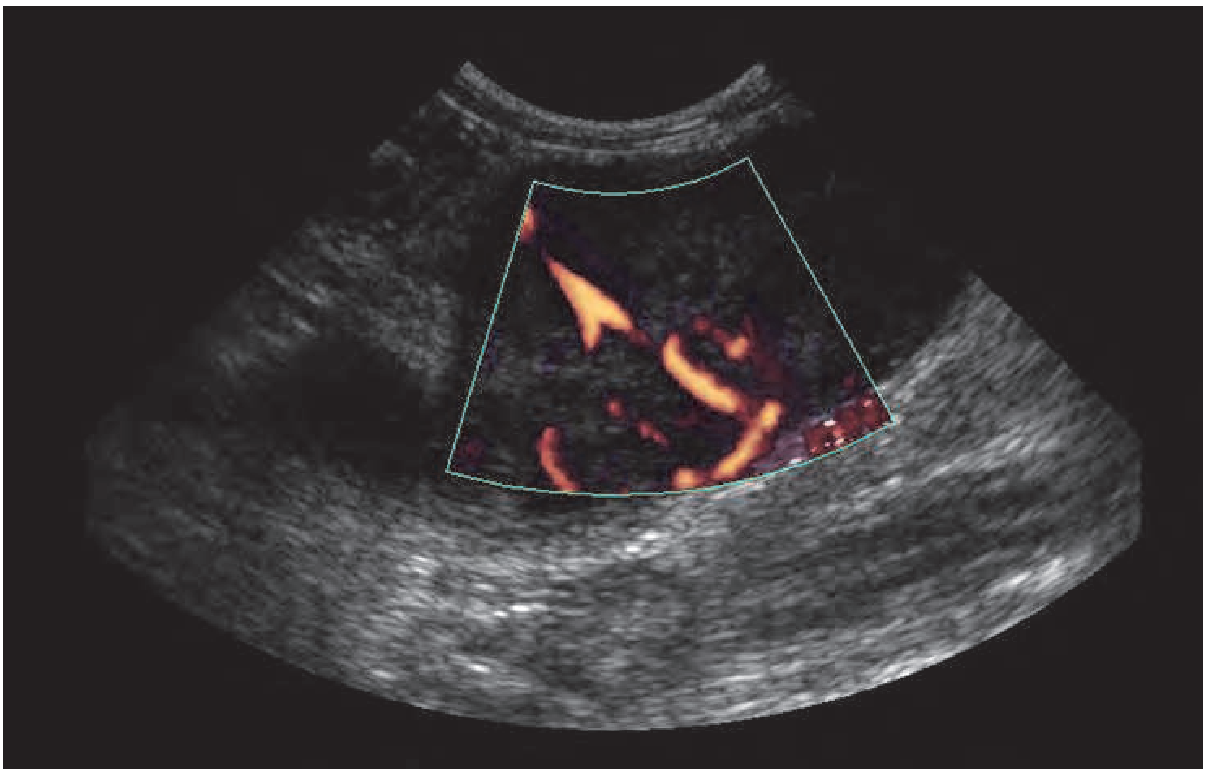

Fig. 8. Metastasic Abdominal lymph node. The vessels could not be displayed using color Doppler, however the Power Doppler used in the image had sensitivity enough

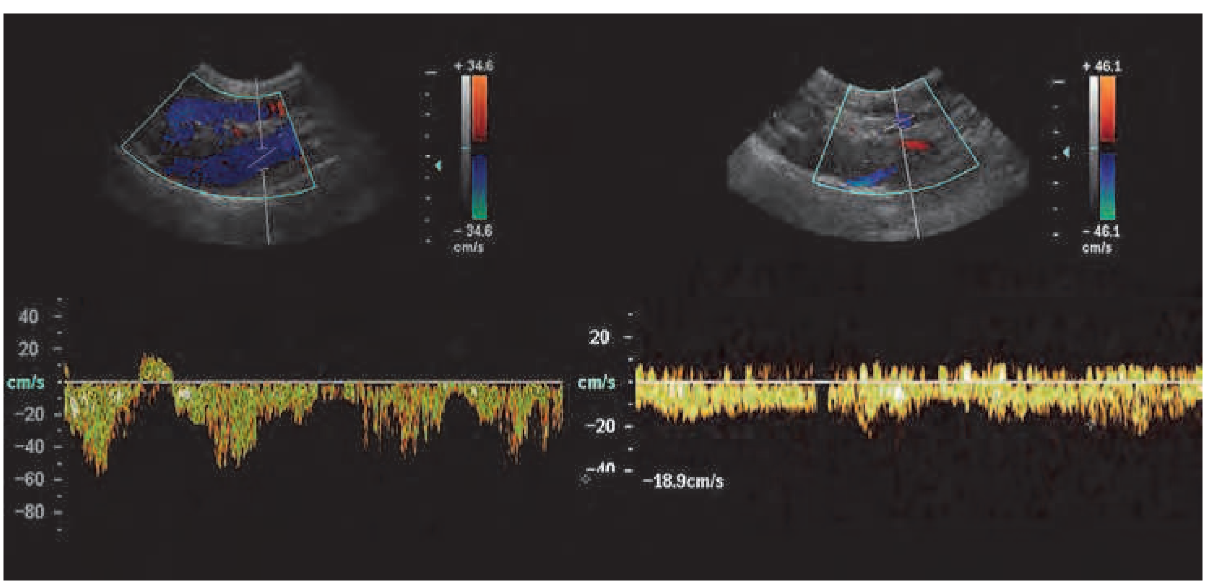

Fig. 9. Left side of the image caudal vena cava spectral trace showing the typical bi- or tri phasic pattern. In the right side portal vein spectral trace.

3. Doppler study in portal hypertension

By means of portal vein Doppler spectral trace it can be easy to diagnose and to monitore portal hypertension (PH). PH is a constant increasing of the venous pressure in the portal system, and it is the main cause of ascites in small animals. For the diagnose of this disease is necessary a broad clinical approach including biochemistry and electrolyte profiles, radiography and the analysis of the free abdominal fluid, although all these diagnostic methods will roughly help as a criteria for the monitoring of the disease. It is in this field where the ultrasound, specially the Doppler study will provide a new tool for its study in small animals. Development of PH is due to the obstruction of the blood flow, initially distending the vascular beed previous to the site of the obstruction. This place will be used as a criteria for the classification of the PH, including: Prehepatic PH (when the vascular area affected is located previous to the hepatic hilus) (Figure 10), Intrahepatic PH (hepatic structures affected) and Posthepatic PH (when the problem is located in the hepatic veins, caudal vena cava or right side of the heart). Prehepatic PH is rare in small animals, and although in the acute forms –portal thrombosis- is associated to fatal prognosis at short term, chronic evolution (pe external compression, neoplasia, etc) is less aggressive and allows for the development of compensatory mechanisms. Intrahepatic PH is the most common type of PH in dogs and cats, being less common in the latest. Almost always is due to abnormal sinusoidal circulation produced either in fibrosis or nodular regeneration in hepatic cirrhosis. Although this is the most frequent mechanism, any diffuse hepatic disease (hepatitis, lipidosis, neoplasia, etc…) may induce portal hypertension. Posthepatic PH is less frequent, and is usually due to the increasing of the resistence in hepatic veins or caudal vena cava, although it can be also produced secondary to alterations in the right side of the heart (constrictive pericarditis, heart worm disease, etc…) .

The study of the portal system by B mode ultrasound provides information about the integrity and shape of the portal vein, and when Doppler is used, we can also obtain quantitative and qualitative information of the flow and velocity. However, the result of the ultrasonographic study can by frustrating if previous factors are not considered, for example the inadequate preparation of the animal, being this the main factor for the proper viewing of the prehepatic tract of the portal vein. When performing the ultrasonographic study, two positions are usually used depending on the window chosen: Left lateral recumbency is the most adequate position for dogs and cats, placing the probe in the 11th or 12th intercostal space, or caudal to the last rib. When the animal is placed in dorsal recumbency, it is easy to access the ventral window caudal to the xiphoid process. The *porta hepatis* is the best place for aquirying the spectral trace, but the sonographer has to consider as a main concern a proper angle correction. Remaining below 60º is acceptable for a reliable velocity profile (Figure 11). The normal trace is quite stable with little or no waves, and we can consider a normal mean velocity for dogs betweeen 12 to 17cm/s and between 10 to 12cm/s in cats. The Doppler evaluation should investigates as well the direction of this flow.

Although the findings in the PH obviously depends on the type (Figure 12), there is a common and reliable one, the decrease in the mean velocity. The flow should be decreased in aproximately a 50% (below 17 ml/min/kg) and the velocity under 10 cm/s. Another consecuence that can be found in a prolonged PH is the development of collateral vessels, known as adquired portosystemic shunts (Figure 13).

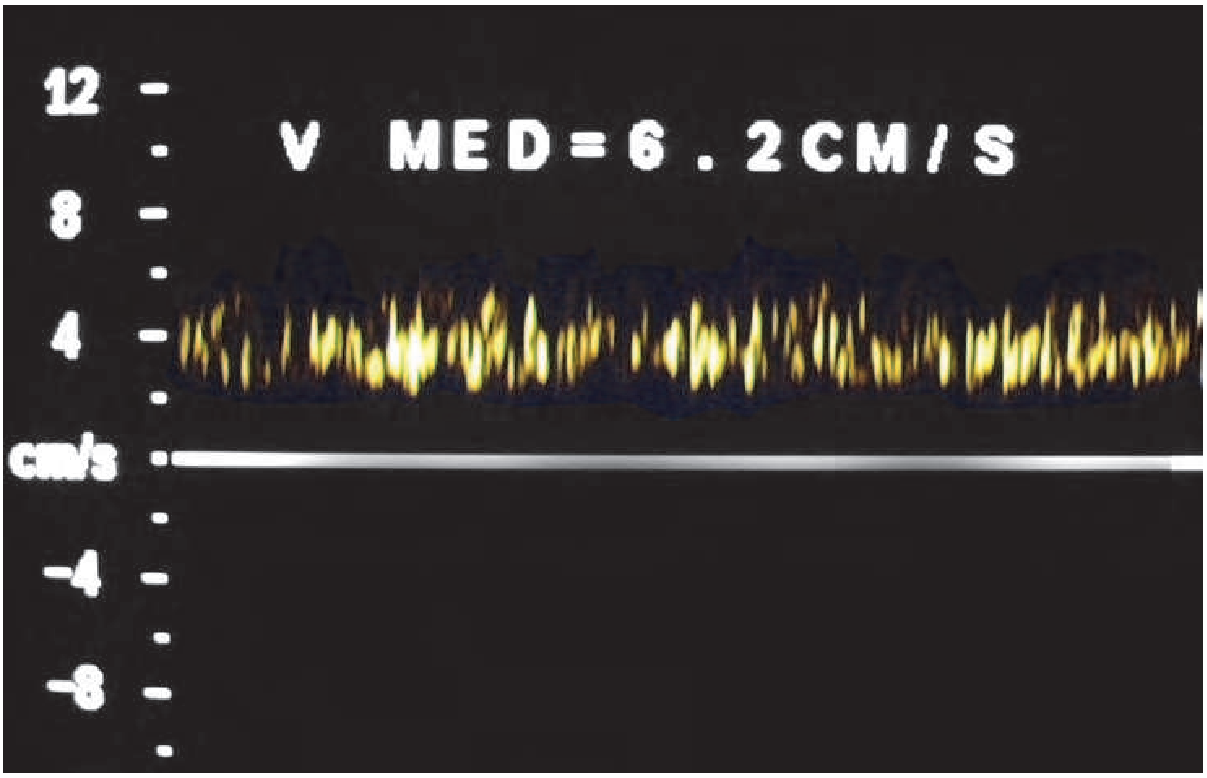

Fig. 10. Spectral trace from a German Shepherd dog with portal hypertension due to a pancreatic carcinoma

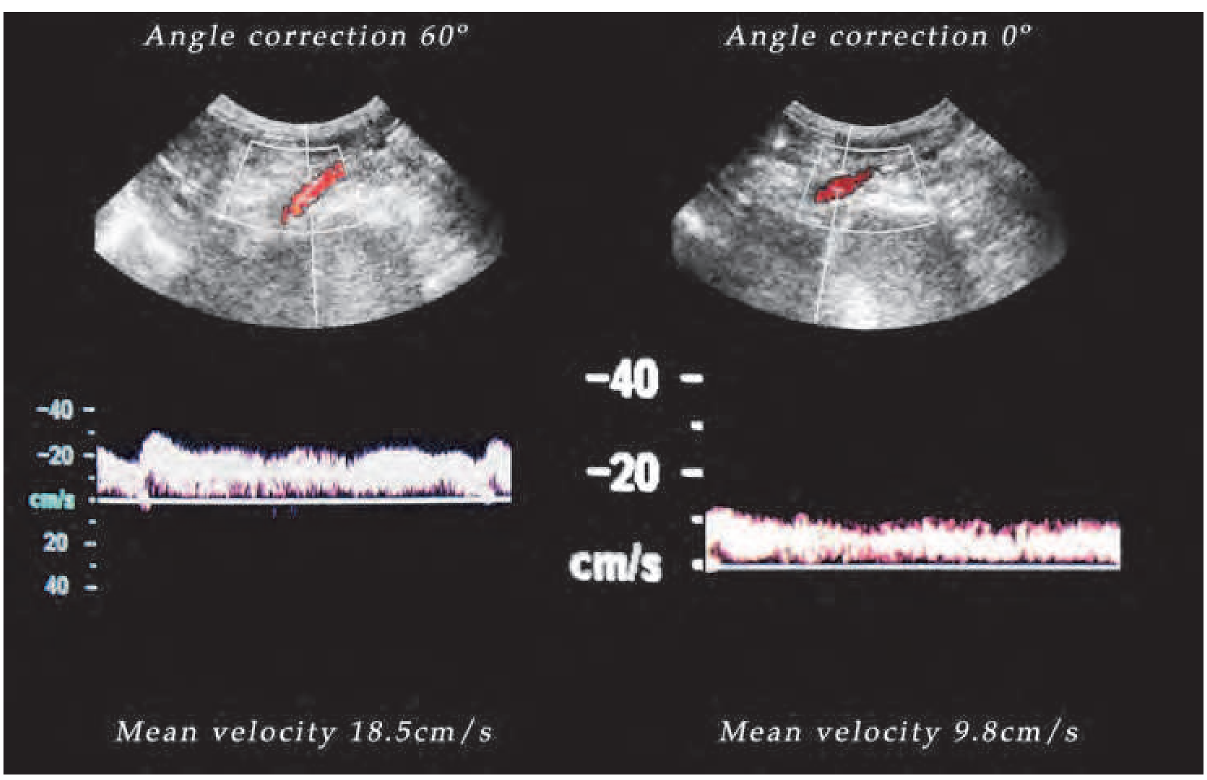

Fig. 11. Different velocity profile retrieved from the same patient using the right angle correction (left) and the wrong one (right)

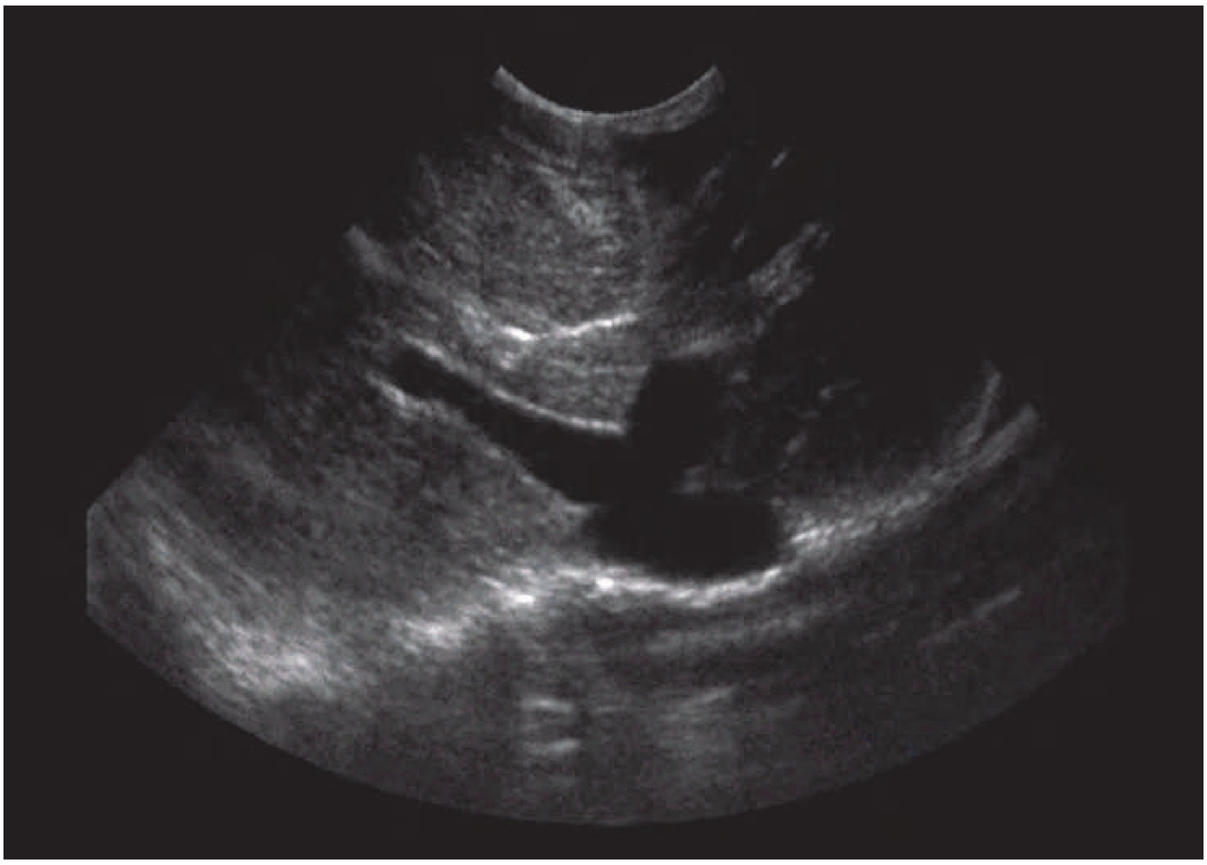

Fig. 12. Portal hypertension in a caval syndrome. The image shows the congestive liver, huge hepatic veins related to portal vessels.

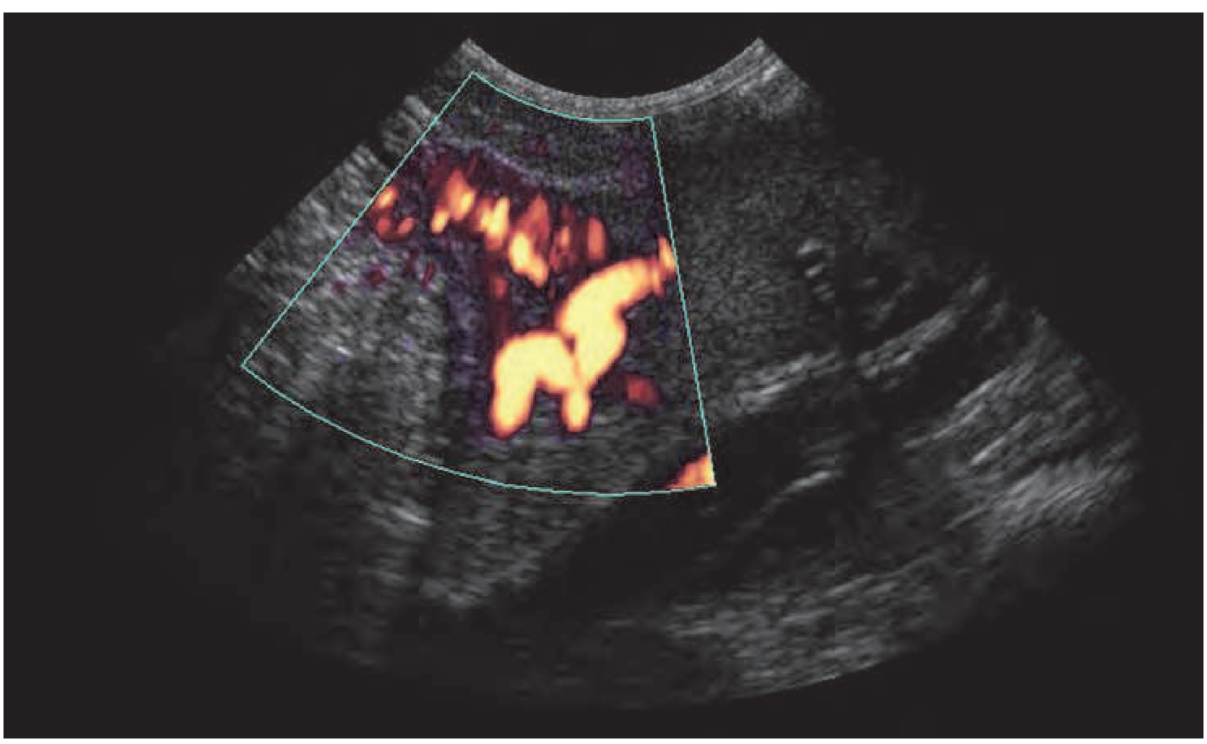

Fig. 13. Tortuous vessels corresponding to nephro-splenic shunts in a dog with chirrosis

4. Doppler assessment of affected lymph nodes

Lymphadenopathy is a common finding in a wide range of diseases. Benign conditions are those related to inflammation induced by infection, trauma, etc. In malignant conditions it is possible to distinguish between primary tumour (lymphoma) and tumour dissemination (metastases). Therefore, lymphadenopathy is a non-specific lesion that merely indicates the presence of a pathologic process. For this reason and taking into account that both conditions can be found in the same patient (e.g. mammary carcinoma in a bitch with cystitis) the real pathologic status of the lymph node must be ascertained. Diagnosis mainly consists of physical examination, which is very subjective and non-specific, needle aspirations and biopsies. These are feasible techniques when dealing with superficial lymph nodes; however they have some inconveniences for abdominal lymph nodes. Sonography plays an important role in this field, being able to explore size, shape and internal appearance. Nevertheless, ultrasonographic changes such as echotexture or size are often inconclusive, the same as guided cytological aspiration (Figure 14).

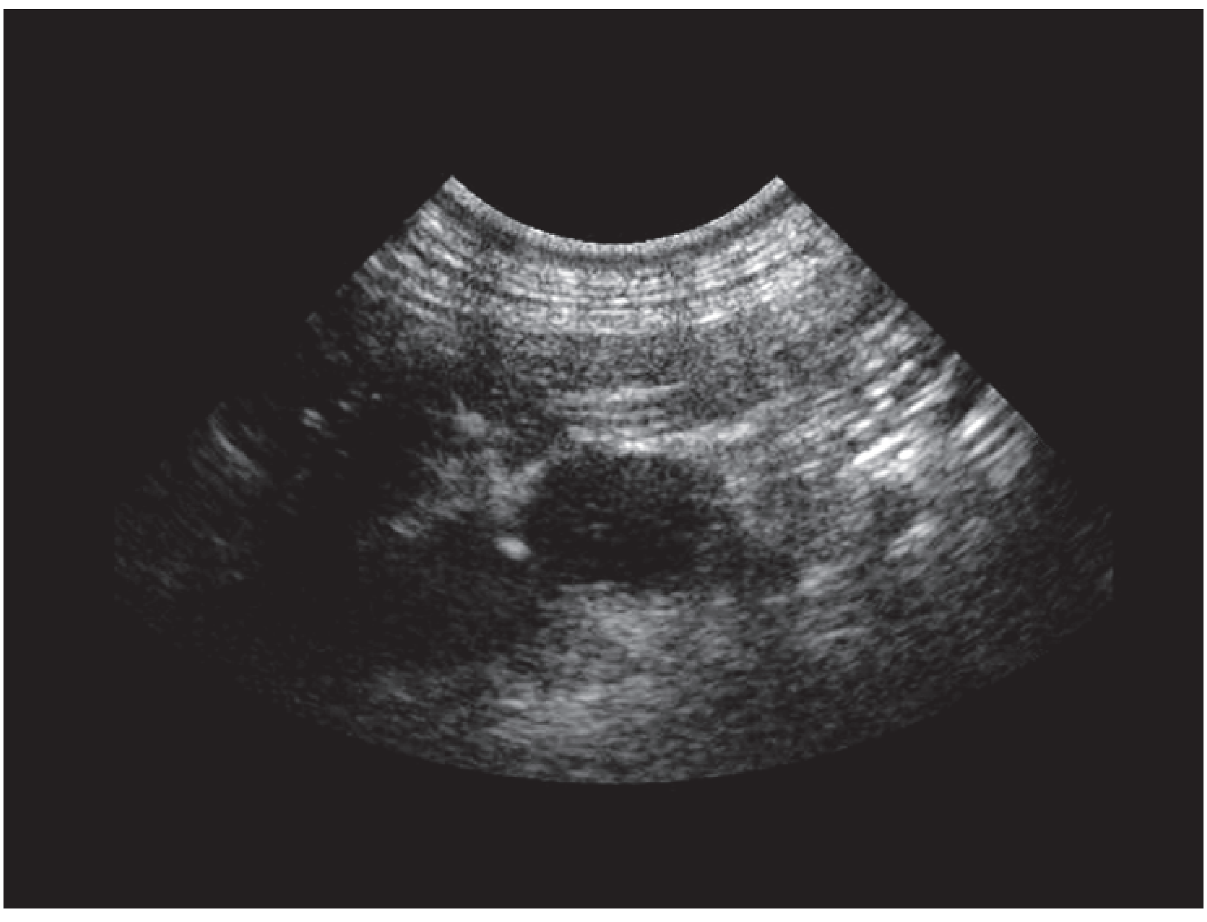

Fig. 14. Fine needle aspiration in a mesenteric lymph node. The 22G needle is clearly visualizad from the right side entering the jejunal lymph node

From a clinical point of view, taking a biopsy of every single lymph node that looks bigger or shows an altered echo pattern would be unpractical. To circumvent these difficulties another diagnostic tool could be used, the Doppler pulse wave analysis of lymph node vessels. This has proved its efficacy in canine superficial lymph nodes, in abdominal ones and in many human medical studies. The first step in the protocol is to look for an internal

lymph node vessel using color Doppler, turning to Power Doppler when necessary. The vessel is later insonated using pulsed wave Doppler to obtain the spectral trace, measuring two semiquantitative indices: Resistive (RI) and Pulsatility (PI). These indices show the relation between arterial flow and the vascular bed. The RI or Pourcelot Index is calculated as follows: (Systolic Peak Velocity – Minimum Diastolic Velocity)/ Systolic Peak Velocity, and the PI or Gosling-King Index is calculated applying this formula: (Systolic Peak Velocity – Minimum Diastolic Velocity)/ Mean Velocity. The final number is obtained using the mean of three arterial insonations in the same lymph node. Two groups of lymph nodes are proposed, benign (healthy plus reactive) and malignant (tumoral or metastasic) a proposed cut-off using the ROC curves had been demonstrated.
The values under which an iliac lymph node is considered benign are 0.6750 for RI and 1.025 for PI. The mean PIs obtained for mesenteric lymph nodes (jejunal) were 0.81, 0.87 and 1.32 for healthy, reactive and tumoral or metastasic ones respectively. The mean RI for the same ones were 0.58, 0.60 and 0.79 respectively. Tumoral or metastasic ones were singnificantly different for PI and RI. The proposed cut-off obtained from the ROC curves with a sensitivity of 100% was 1.23 for the PI and 0.76 for the RI, upper values in a mesenteric lymph node pinpoint to a malignant cause (Figures 15,16).

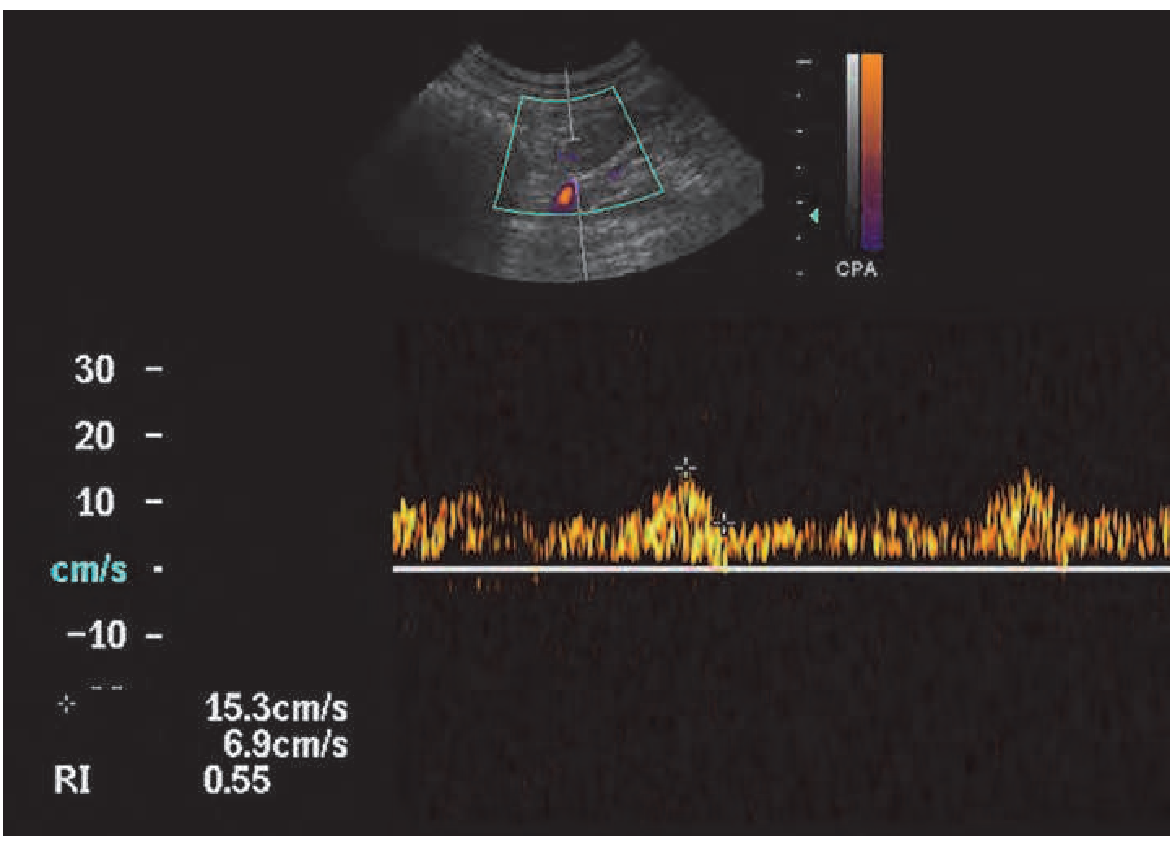

Fig. 15. Spectral trace from a reactive mesenteric lymph node, showing a RI of 0.55

5. Doppler study in renal arteries

The study of the arcuates arteries is the last importat aplication discussed in this chapter. Like the arteries of the lymph nodes, its study reflects the vascular bed. It is essential to obtain a clear spectral trace where three waves are displayed and reliable results can be

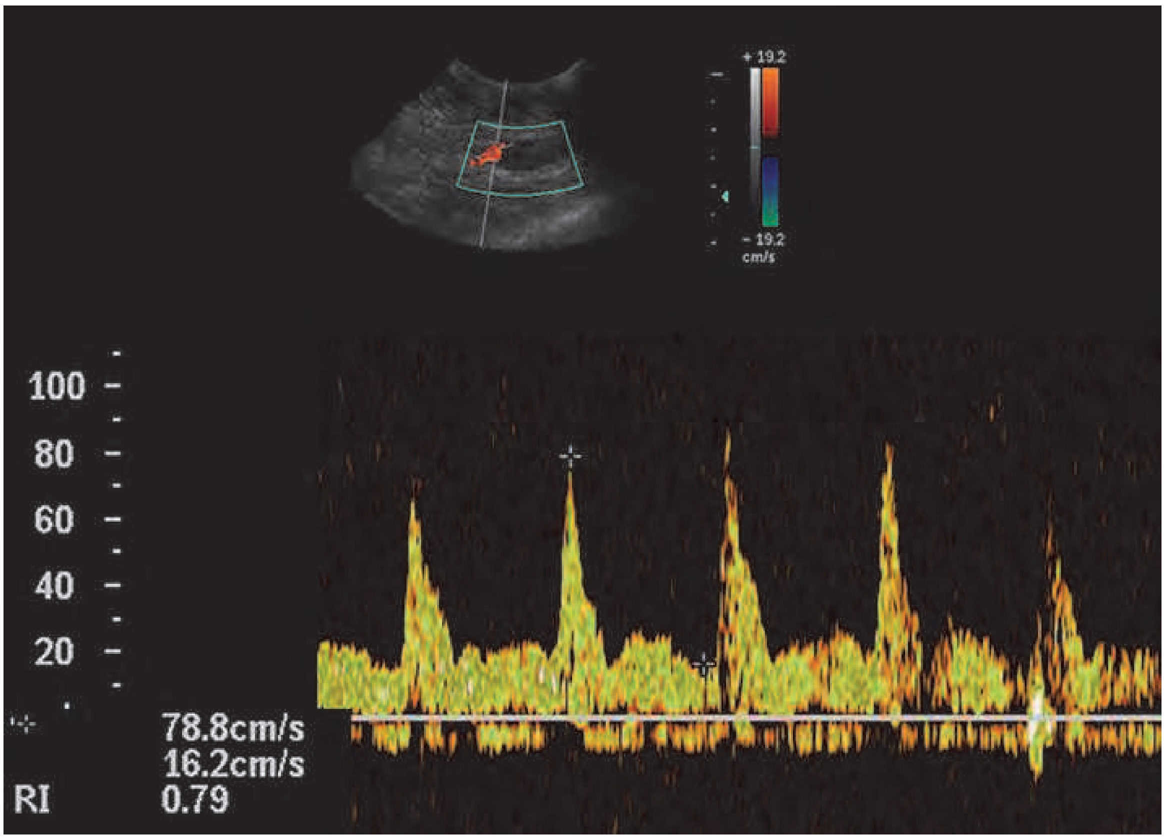

Fig. 16. Spectral trace from a metastasic mesenteric lymph node from a ovaric carcinoma, showing a RI of 0.79

achieved. The resistive index is obtained as the same way as for the lymph nodes and usually indicating the maximal systolic and the minimal diastolic velocities is enough in most of the ultrasound machines to calculate it automatically (Figure 17). Results over 0.75-0.8 are considered abnormal in both dogs and cats. There are processes other than renal diseases that can affect the resistivity index like anaemia, hypovolemic status or hypertension. Thus, further investigation in small animals is necessary to achieve more reliable conclusions, due to most of the published literature proceed from human beings. Since the resistive index is harmless, quick, simple and repeatable, and there are no many available tools for monitoring renal disease, this index should be used as a routine tool in chronic renal failure, diabetes and hyperadrenocorticism. In cats, a raise in this index seems to be linked to tubular damage (Figure 17), although further investigation is necessary in both dogs and cats to relate the type of pathologic lesions with the alteration of this index and clinical signs. As a clinical example, data of a recent study in dogs with Leishmaniosis and different stages of renal damage, showed that the resistive index could be used as an indicator of the progression, with high sensibility but low specificity. In this study all the animals with raised indexes showed advanced renal damage and proteinuria. However, many other dogs with renal damage appeared with a normal resisitve index.

The introduction of the Doppler within the routinary abdominal protocol is necessary, and provides a higher diagnostic accuracy. In coming years new applications of its use will appear as a powerful tool for the diagnosis and monitoring of the diseases in small animals.

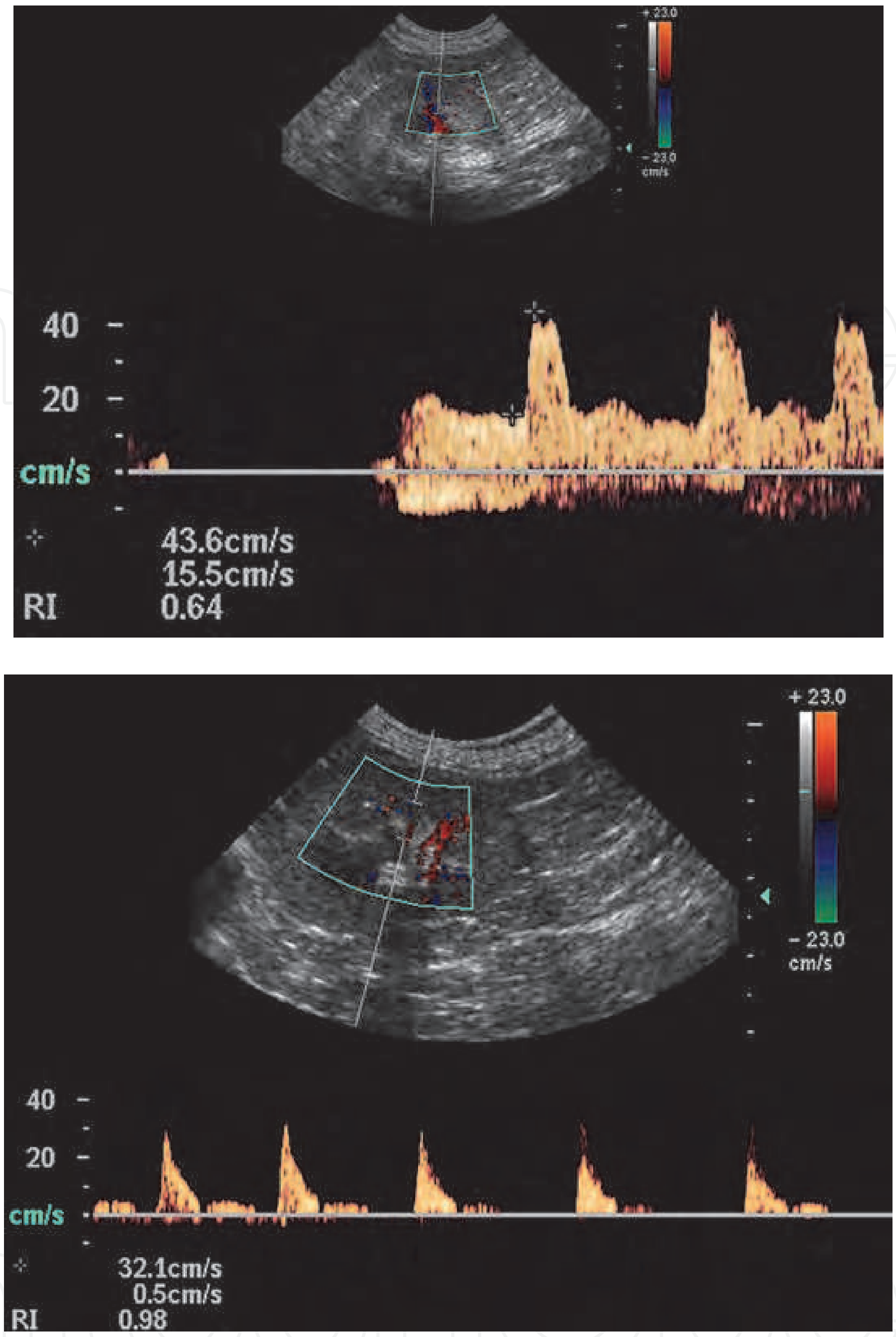

Fig. 17. Normal arquate artery, the spectral trace depicted a low resistence artery, meanwhile in the right there is arquate artery from a cat with advance chronic renal faliure.

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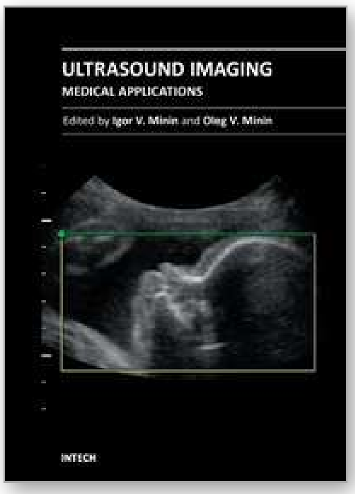

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