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Imaging Modalities for diagnosis of Portal Vein Thrombosis

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Abstract: PVT can be diagnosed by ultrasonography with Doppler imaging, Shear wave elastography computed tomography (CT), and magnetic resonance (MR). Color Doppler ultrasonography (CDUS) is often the first choice of investigation because sensitivity and specificity range from 60% to 100% .Ultrasonography without Doppler imaging does not provide information about flow dynamics. Given its high negative predictive value, if CDUS confirms portal vein patency, then no further studies are required. Shear Wave Elastography is a newer technique that depends on assessing properties of soft tissue to resist a force-induced deformation due to its intrinsic stiffness. Pathological tissues often have less elasticity than the healthy tissue surrounding it. Several ultrasound elastography techniques using different excitation methods have been developed. These techniques are classified into strain elastography, which is a semi-quantitative method that uses internal or external compression for tissue stimulation, and shear wave elastography, which measures the ultrasound-generated shear wave speed at different locations in the tissue. All liver elastography techniques have a standardized examination technique, with the patient in a supine position, while the measurements are performed through the right liver lobe.

Keywords: *Portal Vein Thrombosis, imaging.*

Introduction

The characterization of PVT as neoplastic versus bland is crucial for accurately determining tumor stage and treatment options for hepatic neoplasms, particularly hepatocellular carcinoma (HCC).

The key findings of diagnosis of PVT by contrast CT are :

a)Lack of luminal enhancement in the portal vein.

b)Increased hepatic arterial enhancement in arterial phase films; and

c)Decreased venous enhancement in the liver during the portal phase. **(Ng F. et al.,2013)**.

On the other hand Elastography techniques; depend on measuring shear waves propagation, and permits assessing tissue stiffness in a quantitative way depending on the measurement of the velocity of shear waves **(Taljanovic MS. et al. 2017).**

1) Bland portal vein thrombosis

PVT can be diagnosed by ultrasonography with Doppler imaging, Shear wave elastography, computed tomography (CT), and magnetic resonance (MR).

Ultrasonography with Doppler imaging

Color Doppler ultrasonography (CDUS) is often the first choice of investigation because sensitivity and specificity range from 60% to 100% [15]. Ultrasonography without Doppler imaging does not provide information about flow dynamics. Given its high negative predictive value, if CDUS confirms portal vein patency, then no further studies are required [15].

Ultrasound findings of portal vein thrombosis (Figure 1)

a) Echogenic lesion within the lumen of the portal vein. Loss of venous flow.

b) Portal cavernoma.

c) Inability to identify the portal vein.

d) Dilatation of a thrombosed segment of the PVT [16].

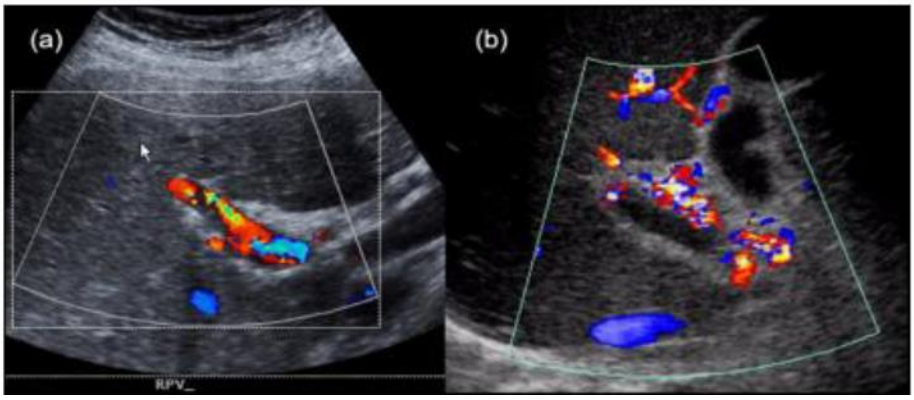

Fig. 1 (A) Doppler ultrasound of the abdomen showing partial thrombosis of the portal vein.(B) Doppler ultrasound of the abdomen showing complete thrombosis of the portal vein [15].

Computed tomography (CT) (figure 6)

Computed tomography (CT) is the second most common imaging test to identify PVT after ultrasonography and may be the best method to define the anatomy of the vascular changes. Intravenous contrast should be used to increase sensitivity. CT is also of value for identifying secondary bowel complications, such as bowel infarction, and underlying pathology like a mass or intra-abdominal infection/ abscess [1]. CT characteristics that can be used to differentiate benign from malignant thrombi. There are three signs; intra thrombus neovascularity, venous expansion (MPV diameter greater than or equal to 23 mm), and direct invasion of the portal vein are independently diagnostic of malignant PVT, their presence precludes any further diagnostic tests. Also, two other signs PVT contiguous with parenchymal hepatocellular carcinoma and generalized enhancement of a PVT-strongly suggest malignant PVT. However, their presence cannot be accepted as absolute evidence of malignant PVT [17].

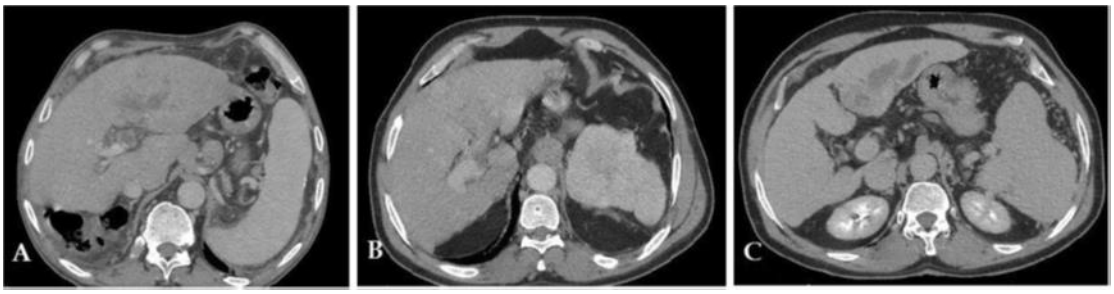

Fig. 2 (A) Triphasic CT infiltrative HCC with malignant left PV thrombus. (B) Triphasic CT left PV malignant thrombus at portal phase. (C) Triphasic CT malignant left PV thrombus washout at delayed phase [10].

Magnetic resonance imaging (MRI) (Fig. 7)

MRI can also be used to evaluate the PVS. The major advantage is the possibility to anatomically evaluate and obtain information about the contents of vascular structures without administering intravenous contrast product and non-using ionizing radiation. However, compared to CT, it is still a more time-consuming, expensive, and less accessible imaging technique, generally with less spatial and temporal resolution necessary to evaluate vascular structures, and also more susceptible to artifacts [10].

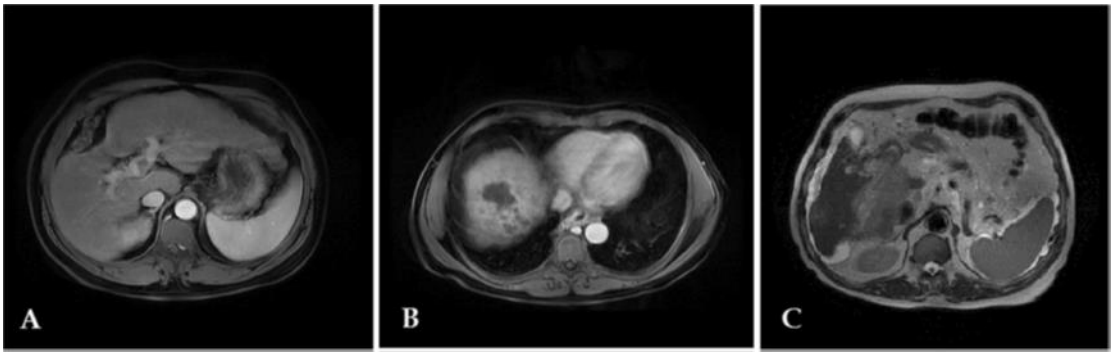

Fig. 3 (A) MRI arterial phase bland thrombus with no enhancement. (B) MRI DWI restricted PV thrombus and HCC at RT lobe. (C) MRI T2WI HCC and malignant PV thrombus lost vascular signal void [10].

Shear Wave Elastography (SWE)

Shear Wave Elastography is a newer technique that depends on assessing properties of soft tissue to resist a force-induced deformation due to its intrinsic stiffness. Pathological tissues often have less elasticity than the healthy tissue surrounding it. Several ultrasound elastography techniques using different excitation methods have been developed. These techniques are classified into strain elastography, which is a semi-quantitative method that uses internal or external compression for tissue stimulation, and shear wave elastography, which measures the ultrasound-generated shear wave speed at different locations in the tissue. All liver elastography techniques have a standardized examination technique, with the patient in a supine position, while the measurements are performed through the right liver lobe [18].

Elastography

Ultrasound elastography is an imaging technology sensitive to tissue stiffness that was first described in the 1990s. It has been further developed and refined in recent years to enable quantitative assessments of tissue stiffness. Elastography methods take advantage of the changed elasticity of soft tissues resulting from specific pathological or physiological processes. Over the last 20 years, the elastographic assessment of several organs with their various diseases, malignancies, and pathologies (such as, liver, breast, thyroid, prostate, kidney, and lymph nodes) has been increasingly developed [19].

Principles and Techniques of US Elastography:

General principle of all elastography techniques; despite their difference; is induction of a tissue distortion, observation and processing the tissue response to determine the mechanical properties of the tissue, and then

presenting the results to the operator, typically as an image. From physical point of view, three terms, stress, strain, and elastic modulus, are required to be understood. Simply, stress is the force per unit area applied to induce a change in the size or shape of a solid, and it is measurable in kilopascals (kPa). Strain is the expansion per unit length of a solid; indicating the response of a solid to the stress (applied force); which is dimensionless and has no unit for measuring [20].

Elastic modulus (elasticity) is stress divided by strain measured in kPa. There are 3 types of elastic moduli (Figure. 8) defined according to the direction of stress and the method of deformation:

1-The Young's modulus E, explains the strain response of the material uniaxial stress in the direction of this stress (like putting a weight above column, or pulling on the ends of a wire with the column becomes shorter and increasing length of the wire), applied force is perpendicular to surface. The Poisson's ratio v, defines the perpendicular response to this uniaxial stress (thinning of the wire and increased thickness of the column) [21].

2. The shear modulus G, which describes the material's response to surface tangential shear stress (such as cutting it with dull scissors), altering its shape but not volume [21].

3. The bulk modulus K, defining the material's response to global (uniform) hydrostatic pressure (like the pressure at the bottom of the sea or a deep swimming pool), affecting volume, not shape of the material with inward pressing stress [21].

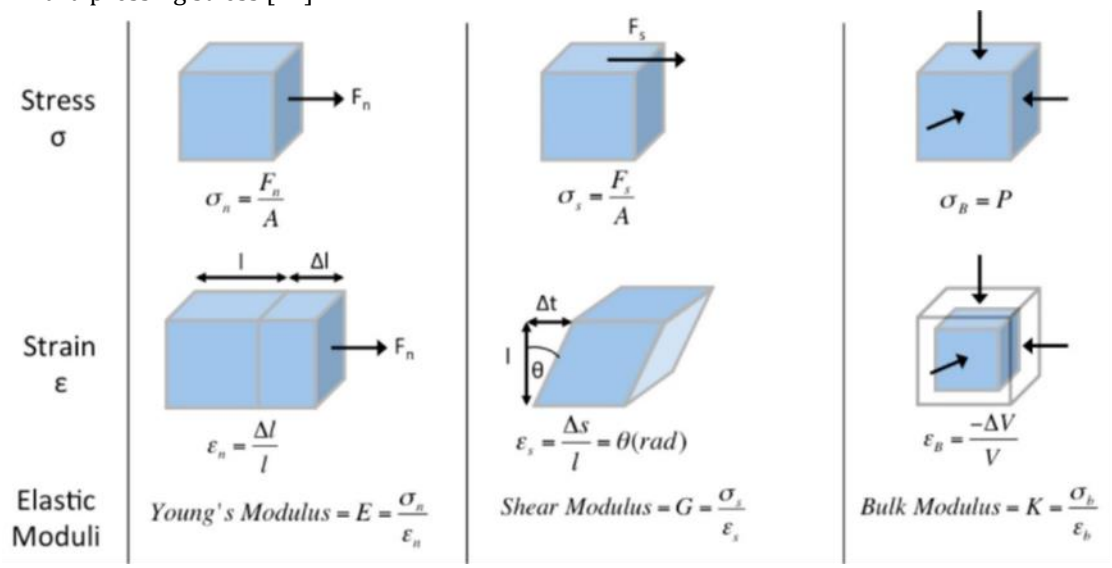

Fig. 4 Ultrasound elastography physics [22].

Radiological techniques:

US elastography that could be either strain or shear wave.

Magnetic resonance (MR elastography)

US elastography techniques:

Strain imaging: applying a stress to a particular tissue then measuring the strain allowing a quantitative application of Young's modulus. It is strain elastography (SE) and ARFI strain imaging that were the first US elastography techniques used [20].

2- Shear wave imaging (SWI): a dynamic stress is applied to the tissue with either a mechanical vibrating device in TE or acoustic radiation force in point shear wave elastography (pSWE) or two dimensional shear wave elastography (2D-SWE). Shear waves are produced perpendicular to the acoustic radiation force applied or parallel to the TE excitation. Shear wave velocity is measured, or Young's modulus E is estimated and recorded [20].

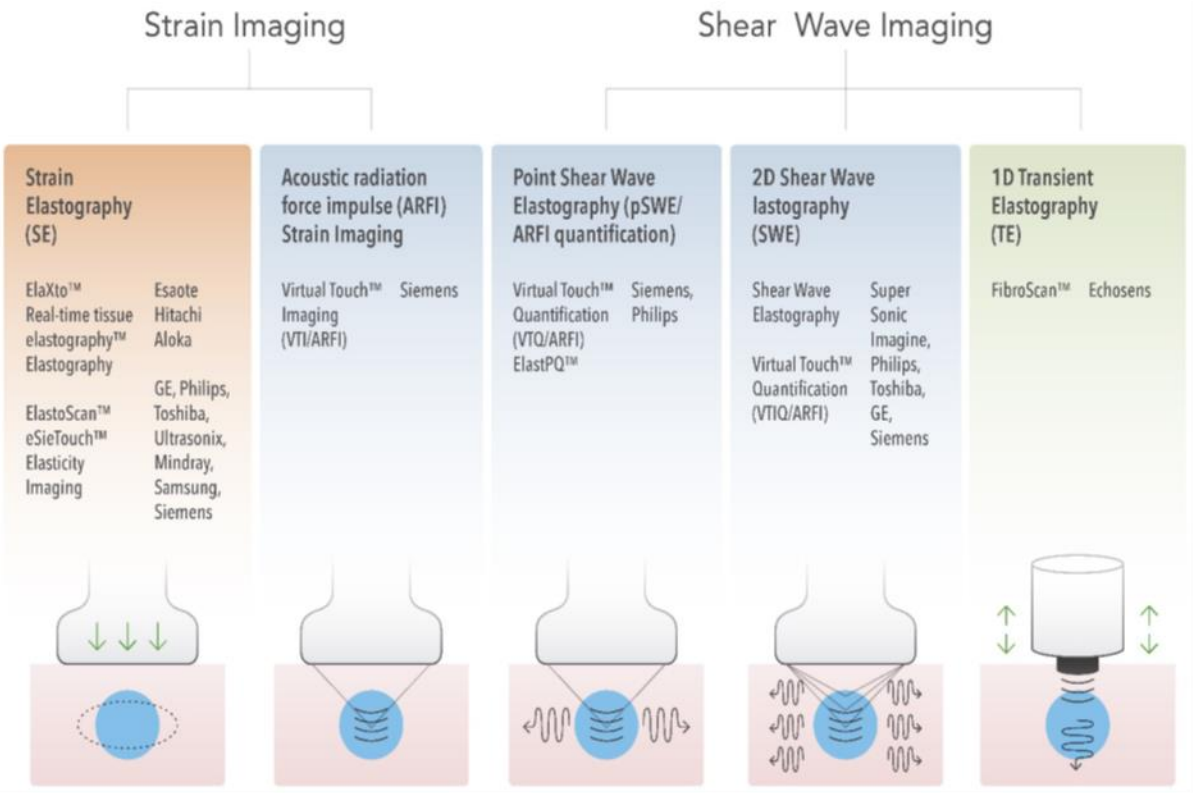

Fig. 5 Ultrasound Elastography Techniques [22].

Strain elastography (SE):

In this technique, either by manually compressing the tissue using the US probe, the excitation process can be used to test superficial organs such as the breast and thyroid, or by internal physiologic motion (e.g. cardiovascular, respiratory) with the US transducer is held steady [23], it can be used to assess deeper organs as liver. The US images before and after the compression are compared, with the least deformed parts of the image are the stiffest which is diseased parts, while the most deformed areas are the least stiff which is either healthy or less diseased [22]. An elastogram is a semi-transparent color map displaying the strain measurements, which is overlaid on the B-mode image. Blue color displays low strain (stiff tissue), while red color displays high strain (soft tissue), and the color scale can vary according to the US system [24].

SE is essentially qualitative as the manually or physiologically applied stress is not quantifiable, but a qualitative measure of Young's modulus E and thus tissue elasticity can be provided by assuming uniform normal stress with measured normal strain [25]. Pseudo-quantitative methods were attempted to represent SE. Strain ratio, which is the ratio of a measured strain in normal tissue surrounding the diseased region, to that of diseased region. An increased strain ratio indicates that the target lesion is stiffer than the normal reference tissue with less compressibility [26]. Elastogram/B-mode size ratio is another pseudo-quantitative method which is the ratio of the size of the tumor in an elastogram to the size of the same area in B-mode that have been used [19].

Acoustic radiation force impulse (ARFI):

This technique assessing tissue displacement caused by a short duration (0.1-0.5 msec) high-intensity focused US beams "pushing pulse" called acoustic radiation force, that can displace tissue (displacement of~ 10-20 μm) in the same direction of the beam, i.e. perpendicular to the surface [27]. As SE, tissue displacement is reported by imaging the tissue before and after applying focused acoustic radiation force 'push' pulses. Tissue displacement is directly related to the strength of the applied force and contrary to the tissue stiffness [28].

ARFI imaging does not based on pressing over the transducer as SE, so it is not operator dependent and capable of focusing the 'push' within deeper organs. However, as with SE, nonlinear tissue reaction can be produced by transducer pressing, so slight compression is required during ARFI imaging [19].

One-dimensional transient elastography (TE):

TE has been designed only for liver elasticity measurement. It uses an automated piston, which is also a disk-shaped ultrasound transducer, that applies a low frequency (50 Hz) mechanical push to the body surface with controlled applied force. A transient shear wave is created that propagates into the tissue. The shear wave propagation velocity is proportional to tissue stiffness, which increases with fibrosis [22]. TE measures tissue stiffness over a 1 cm diameter and 4 cm length region of tissue, which is 100 times larger than those evaluated with liver biopsy. The transient shear wave deformation is propagated at a constant speed, for 4 cm, and measured by a straight line automatically displayed in a displacement M-mode. If the pulse is not transmitted and recorded successfully, the software does not provide a reading. Transient elastography is marketed under the trade name FibroScan®. Stiffness values are presented in kPa. Controlled attenuation parameter (CAP) is a technology that quantifies liver steatosis by measuring the energy loss as the sound wave passes through the medium. Total attenuation at 3.5 MHz is expressed in dB/m, and steatosis is estimated using the same radiofrequency data as elastography, in the same location that stiffness is measured [29].

Point shear wave elastography (pSWE):

This technique uses a high-frequency ARFI (push pulse) focused on spot (region of excitation (ROE)), which is then absorbed as acoustic energy. This absorbed acoustic energy expanding the tissue, resulting in shear waves orthogonal to the axis of US beam. The shear wave displacement developed by the push pulse is detected by an US probe with a series of tracking or detection pulses at the region of interest (ROIFrom these informations, the speed of the shear wave can be measured and reported in meters per second, or in Kilopascal when converted into the Young's modulus [27].

PSWE is incorporated in regular US systems that can concurrently produce the conventional gray scale B-mode images, permits selection of an ROI in a representative area of the liver and this region can be saved and followed up for monitoring. It is better than TE in local production of shear waves inside the tissue and so can transmitted in obese patients or with ascites. However, some limitations are found regarding pSWE, it is more expensive, needs a radiologist or sonographer and more expertise than TE, and the technique is less suitable for point of service [28]. Fluctuation in measurements between different probes and manufacturers, which greatly limits SWE use as the frequency of the shear wave is difficult to control and tissue absorption of energy is increased [20].

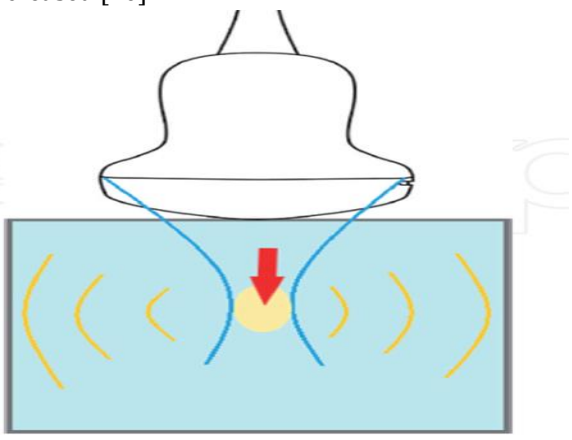

Fig. 6 Schematic representation of the principle of point shear wave elastography (pSWE). An ultrasound-induced focused radiation force impulse is produced at a controlled depth generating a lateral shear wave in a region of interest (ROI). The measured shear wave speed represents tissue stiffness [30].

Two dimensional shear wave elastography (2D-SWE):

It is the most recent US SWI method relies on acoustic radiation force 2D-SWE interrogates multiple focal zones along ARFI axis in a more rapid manner than shear wave velocity (rather than a single spot as in ARFI strain imaging and PSWE) producing a cone-shaped shear wave field, in addition to its ability to obtain an ultra-high frame rate (up to 15,000 images per second) (Figure. 11).

Both characters of cone shaped shear wave field and ultra-high frame rate, facilitate generation of real-time elastograms of the entire ultrasonic plane of the examined tissue and measurement of shear wave velocity in m/s or Young's modulus E in kPa [22].

The benefits of this technique include real-time visualization of a colored elastogram overlaid on a B-mode image, which helps the operator to be directed by both anatomical and tissue stiffness data. But it is still of limited availability that making performed researches little to provide a full data for its use [31].

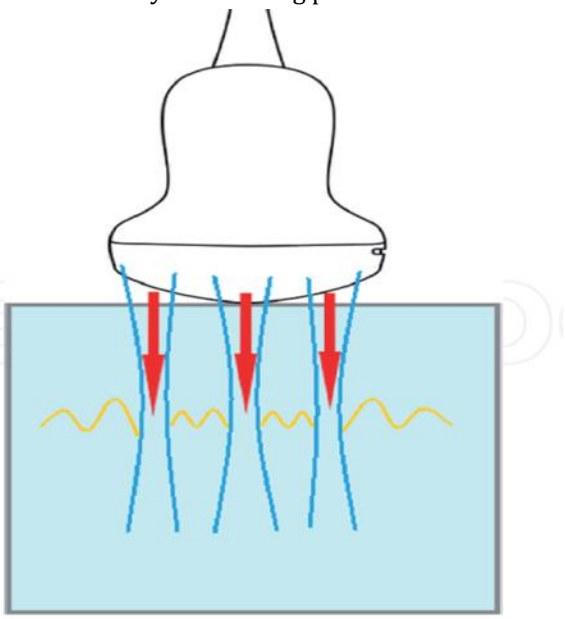

Fig. 7 Schematic representation of the principle of 2D shear wave elastography (2D-SWE). Multiple ultrasound-induced ARFI lines create transverse shear waves that produce quantitative images of their speed [30].

Imaging appearance

The characterization of PVT as neoplastic versus bland is crucial for accurately determining tumor stage and treatment options for hepatic neoplasms, particularly hepatocellular carcinoma (HCC).

The key findings of diagnosis of PVT by contrast CT are:

a) Lack of luminal enhancement in the portal vein.

b) Increased hepatic arterial enhancement in arterial phase films; and

c) Decreased venous enhancement in the liver during the portal phase [13].

On the other hand Elastography techniques; depend on measuring shear waves propagation, and permits assessing tissue stiffness in a quantitative way depending on the measurement of the velocity of shear waves [18].

Imaging appearance of different causes of portal vein thrombosis;

Liver Cirrhosis

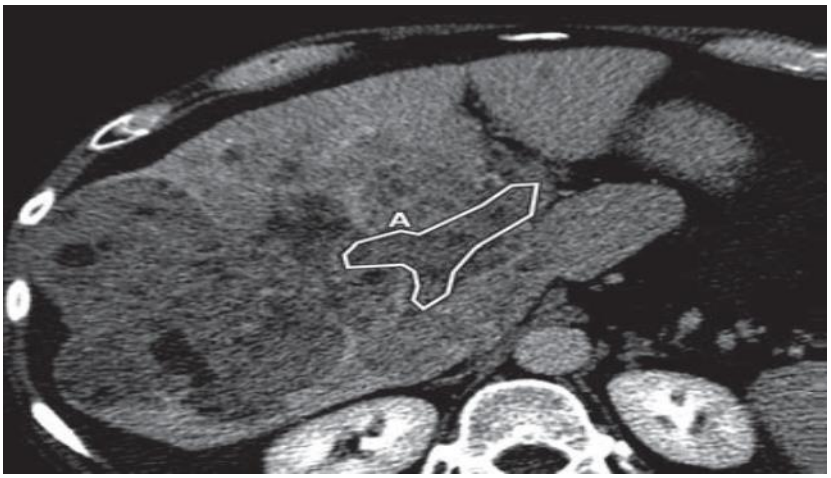

Fig 8 CT showes patient with cirrhosis and infiltrative hepatocellular carcinoma. Axial contrast-enhanced CT (CECT) image in portal venous phase shows ROI (A) drawn around neoplastic portal vein thrombus [4].

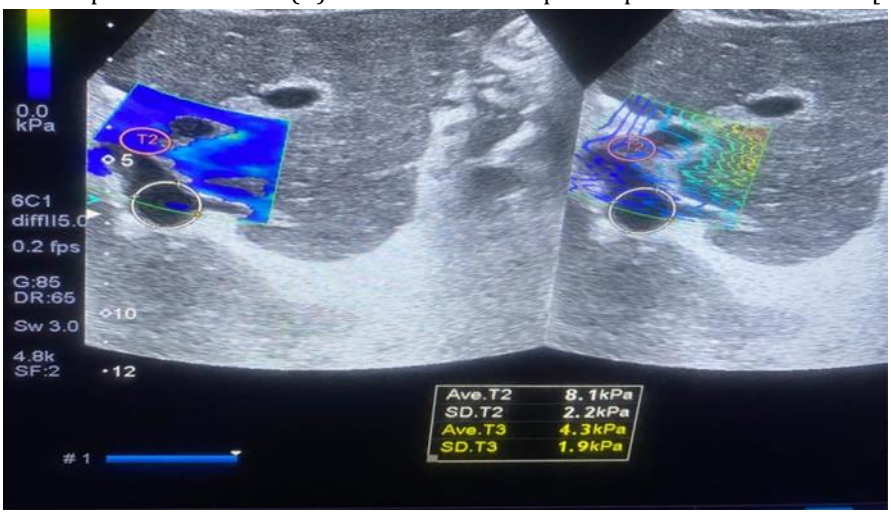

Fig. 9. 2D shear wave elastography of liver and portal vein shows Portal Vein thrombosis. Malignancies; most commonly Hepato Cellular Carcinoma

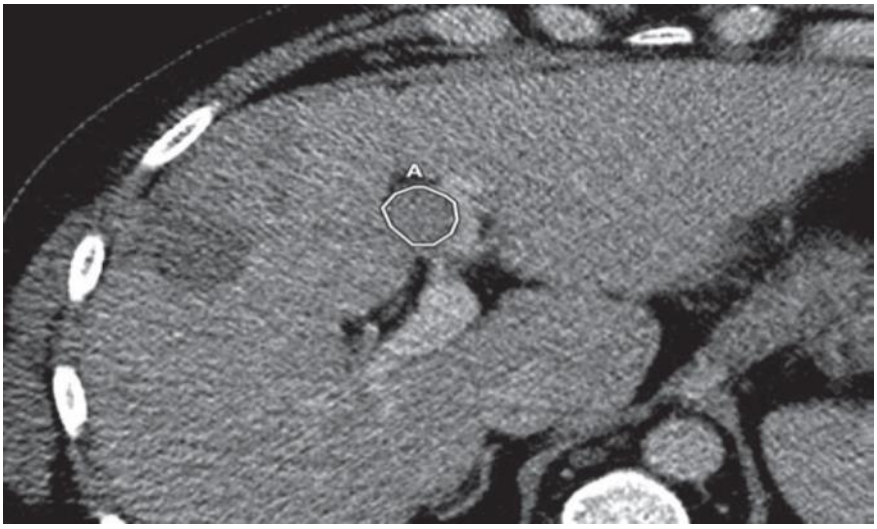

Fig 10 Axial portal venous phase CT shows neoplastic thrombus (ROI, A) in left portal vein [4].

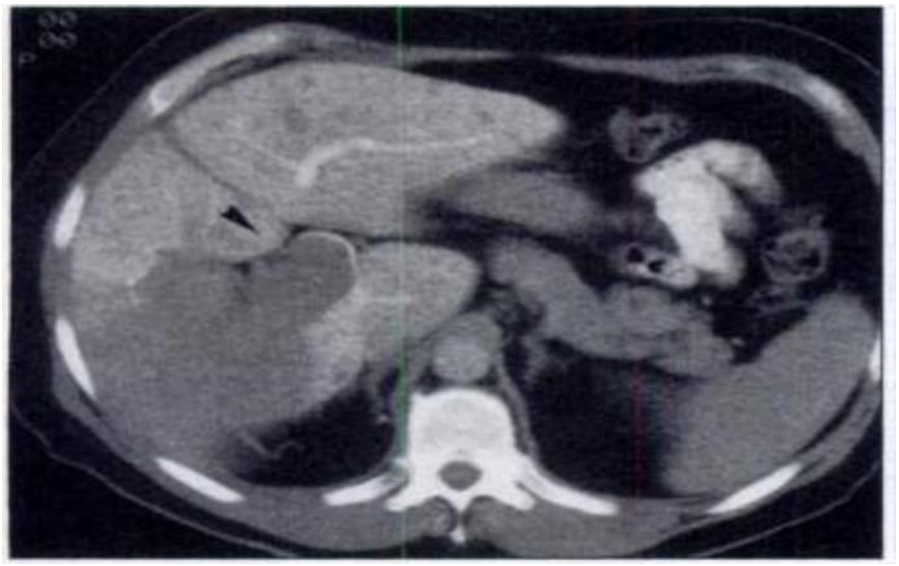

Fig 11 Contrast-enhanced CT scan shows direct extension of hepatocellular carcinoma into right and main portal veins (Malignant portal vein thrombus.). Note marked expansion of portal vein by malignant thrombus (arrowhead) [17].

Bland portal vein thrombosis

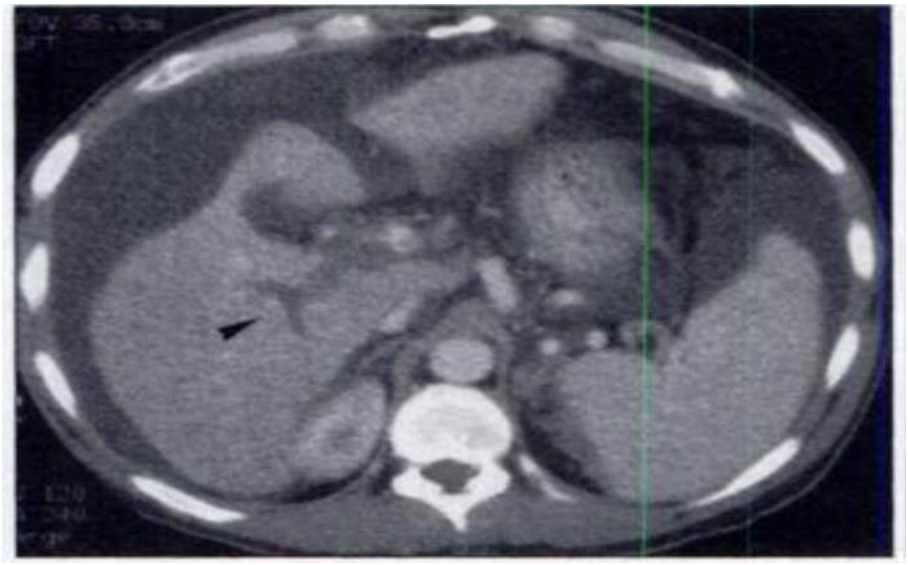

Fig 12 Contrast-enhanced CT scan shows occlusive thrombus within right portal vein (arrowhead). Note lack of expansion of portal vein by thrombus (Bland portal vein thrombus) [17].

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