

Doppler assessment of maternal central venous hemodynamics in uncomplicated pregnancy: a comprehensive review

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Introduction

Doppler studies on haemodynamics of the cardiovascular system and intra-abdominal organ perfusion in non-pregnant individuals are usually performed by cardiologists and radiologists. Specialists in Maternal-Fetal Medicine are also familiar with cardiovascular Doppler sonography, however, they mostly focus on the fetal (Malcus, 2004) or utero-placental circulation (Abramowicz and Sheiner, 2008; Papageorghiou and Leslie, 2007; Cnossen *et al.*, 2008). Recently, several studies have been reported using Doppler assessment to explore the dynamics of the maternal venous compartment, illustrating its feasibility and reproducibility (Karabulut *et al.*, 2003; Bateman *et al.*, 2004; Roobottom *et al.*, 1995; Gyselaers *et al.*, 2009b; Gyselaers *et al.*, 2008; Gyselaers *et al.*, 2009a). These studies have shown that the venous compartment is also subject to maternal cardiovascular adaptation during uneventful pregnancy (Gyselaers *et al.*, 2009b; Gyselaers *et al.*, 2009a). In gestational diseases, such as preeclampsia, some of the observations show promising results with respect to detecting maternal cardiovascular maladaptation (Gyselaers *et al.*, 2009b; Gyselaers *et al.*, 2009a) and predicting the development of subsequent disease (Gyselaers and Mesens, 2009). Therefore, the maternal venous compartment is a new area to be explored in obstetric ultrasound imaging (Gyselaers, 2008), in order to link Doppler observations to known features of gestational (patho)physiology

(Gyselaers *et al.*, 2009b; Gyselaers *et al.*, 2009a) and to the information obtained from other techniques (Carty *et al.*, 2008).

This paper offers a comprehensive review on Doppler assessment of the maternal venous compartment during uncomplicated pregnancy.

Literature sources

A literature search was conducted to identify all the published observational Doppler studies on maternal venous haemodynamics. Relevant citations in PubMed and Medline were searched using combinations of the keywords: Maternal Physiology, Doppler, Hepatic Veins, Renal Interlobar Veins, Pregnancy, Venous Hemodynamics, Venous Compartment, Central Veins, Gestational Cardiovascular Adaptation, Review. The reference list of all known primary and review articles was examined for additional relevant citations. Relevant chapters from handbooks were searched in the Library of Hasselt University and in the author's personal collections.

Definition and anatomy of the lower central venous compartment

The venous system is responsible for the return of deoxygenated blood from the organs back to the heart. The central veins are the large single lumen veins, which are anatomically located in the vicinity of the heart. Basically they include the jugular veins, the upper and lower vena cava, the hepatic veins, and

the renal veins. The blood in the central veins flows undisturbed into the right atrium, as there is no interposition of an anatomical or functional valve. The anatomical structure known as the valve of the inferior vena cava (VCI), first described by Eustachius (Hickie, 1956), is a non-occlusive semi-lunar endocardial fold at the anterior site of the entrance of the VCI in the right atrium, which directs the oxygenated blood towards the open foramen ovale during foetal life, but degenerates after birth (Hickie, 1956). As a result, intravascular measurements of venous pressure, flow velocities and volumes in the central veins mirror the function of the right heart (Boulpaep, 2005b; Berne and Levy, 2001a). In clinical practice, this principle is commonly used to estimate central venous pressure at the level of the jugular veins using both non-invasive and invasive methods (Magder, 2006).

As illustrated in Figure 1A, the liver drains blood into the VCI through the hepatic venous tree, which consists of three main branches: the left, middle and right hepatic veins (HV). Sometimes, an accessory inferior right HV is found (Neumann *et al.*, 2006). Right and left HV, respectively, drain the largest and smallest liver volumes (Neumann *et al.*, 2006). Hepatic veins are the sole exit of blood from the liver, and drain blood originating from both the portal vein and hepatic arteries (Grant *et al.*, 1992).

As illustrated in Figure 1B, the right Renal Vein (RV) is located more caudally and is half as long as the left RV, which is the one crossing the midline and draining blood from the left ovarian vein. The left

RV is squeezed between the aorta and the Superior Mesenteric Artery, and sometimes this may provoke orthostatic haematuria (Ahmed *et al.*, 2006). This so-called Nutcracker phenomenon may aggravate during pregnancy (Itoh *et al.*, 1997). Compared to the left side, accessory renal veins are more frequent on the right side and the proximal RV diameter is larger (Satyapal *et al.*, 1995a; Satyapal *et al.*, 1995b).

The anatomy of the lower central venous system differs widely between individuals, not only because of a high frequency of accessory veins as mentioned above, but also because of asymptomatic congenital variations. These congenital anomalies are found in all segments of the VCI (Fernandez-Cuadrado *et al.*, 2005) and have to be taken into account in the pre-operative work-up of liver- or kidney transplantation (Mathews *et al.*, 1999; Pannu *et al.*, 2001). Next to this, different types of congenital intrahepatic vascular shunts have been observed, such as arteriovenous connections, arteriportal shunts and portosystemic fistulas (Gallego *et al.*, 2004). Both congenital aberrations and intrahepatic vascular shunts are responsible for a wide inter-individual variation in hepatic vein Doppler patterns in healthy subjects (Pedersen *et al.*, 2005).

Physiology of venous hemodynamics

The venous compartment had an important role in human physiology. It is a large capacitance reservoir, containing 65-75% of the total blood volume, 75% of which residing in small veins and venules (Pang,

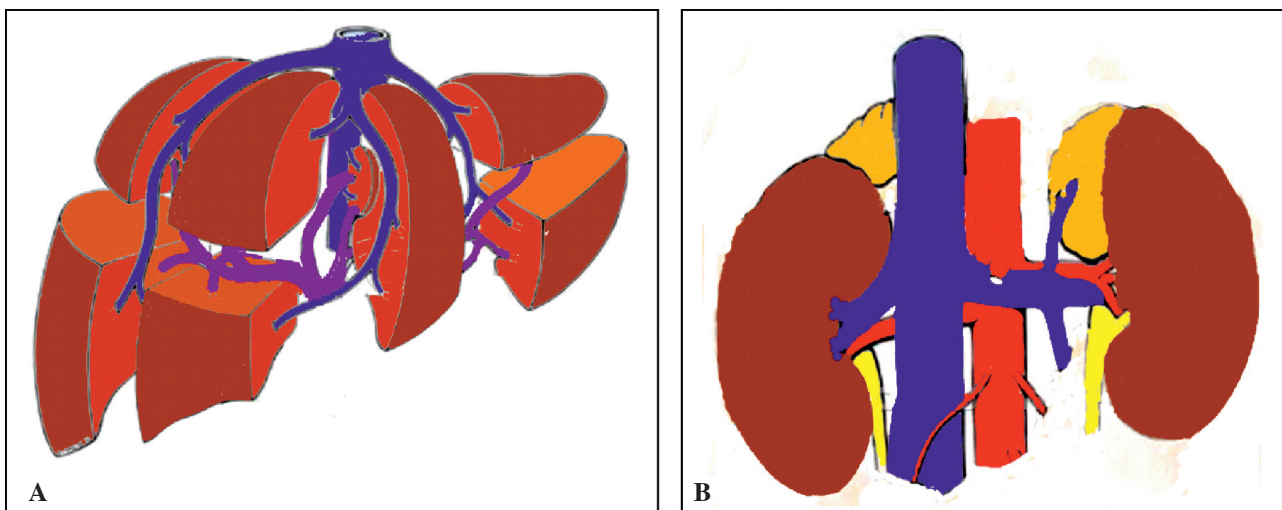


Fig. 1. — Anatomy of the lower central venous compartment from liver to kidneys. As is shown in the left panel, there are 3 hepatic veins (HV): left, middle and right, which are often accompanied by additional branches. Usually, left and middle HV fuse before draining into the vena cava inferior (VCI) at a few centimeters caudal from the right cardiac atrium. The right panel shows that the right renal vein (RV) is shorter and inserts more caudally into VCI than the left RV. Next to this, the right RV has more accessory branches and a wider proximal diameter than the left RV. Also, the left LV is sometimes sandwiched between Aorta and Superior Mesenteric Artery (Nutcracker Syndrome) and drains blood from the left ovarian vein.

2000). The splanchnic bed is the most important blood reservoir of the body, containing up to 25% of the total blood volume (Pang, 2000), most of it located in the liver bed (Berne and Levy, 2001b). The venous walls contain collagen and elastin fibres, together with a circular layer of smooth muscle cells (Juncqueira and Carneiro, 2005). This structural composition enables physiologic properties such as expansion, visco-elasticity and active contraction (Pang, 2000). As such, the venous compartment contributes actively to the regulation of cardiac output (Boulpaep, 2005a; Berne and Levy, 2001a). Contrary to the arterial system, small changes of intravenous pressure have a major impact on cardiac output (Berne and Levy, 2001a). In the control and regulation of cardiac output, the heart and veins cooperate as one functional unit (Berne and Levy, 2001a). Both structural and functional properties allow the venous system to serve as the main regulator of the circulating blood volume: in case of hypovolaemia (e.g. after haemorrhage), reflex-induced venoconstriction mobilises stored blood from the venular bed to preserve the venous return to the heart, whereas in case of blood volume expansion (e.g. pregnancy), most of the surplus volume is retained in the venous compartment.

The driving force of blood flow differs between arteries and veins. In the arterial compartment, the ventricular contraction creates a positive pressure-gradient between heart and arterial bed, moving the blood at a certain pressure towards the systemic microcirculation. Conversely, in the venous compartment relaxation of the heart during diastole creates a negative pressure gradient between the peripheral veins on the one hand, and the central veins and heart, on the other hand. This suction force is the most important driving force for venous return (Berne and Levy, 2001a; Boulpaep, 2005b).

Many physiologic variables are known to interfere with venous return and the shape of the venous pulse waves. Respiratory movements, particularly the inspiration, are responsible for raising the venous pulse waves (Lewis, 2005; Teichgraber *et al.*, 1997). This may be counteracted by intraluminal obstruction, such as thrombi, or by external compression from intrapelvic masses (Lewis, 2005). An example of this is the gravid uterus, which is responsible for a rise of intravenous pressure of the femoral vein (de Swiet, 1998). Orthostasis and gravity tend to reduce venous return, whereas posture change from an upright to a supine position tends to raise venous return temporarily (Boulpaep, 2005a; Berne and Levy, 2001a). Veins, surrounded by skeletal muscular tissue, depend largely on contractions of these muscles to accelerate venous flow and to prevent stasis of blood. This is mainly true for the lower

extremities, where this muscle pump activity is supported by mechanical compression from stockings for the prevention of deep vein thrombosis in cases of reduced mobility (Roderick *et al.*, 2005). Several drugs and medications have been studied with respect to direct or indirect activity on venous wall muscular contractility (Pang, 2001).

Study of venous hemodynamics by Duplex Ultrasonography

Methods to study body venous tone have been reviewed by Pang (Pang, 2000): they include the measurement of the mean circulatory filling pressure, the constant cardiac output (CO) reservoir technique, plethysmography, blood-pool scintigraphy, linear variable differential transformer technique and intravascular ultrasound. These techniques all have limitations and are difficult to perform in a clinical setting, especially during pregnancy. Duplex Ultrasonography has been reported to be a simple, non-invasive and easily-accessible method to study venous haemodynamics, both in nonpregnant (Downey, 2005) and pregnant subjects (Karabulut *et al.*, 2003; Bateman *et al.*, 2004; Roobottom *et al.*, 1995). Because of high intra- and interobserver variations reported for Doppler-derived measurements (Lui *et al.*, 2005; Nakai and Oya, 2002), methodologic standardisation is needed, especially when interfering factors, as mentioned previously, are to be excluded.

A standardised Duplex Ultrasound examination has been reported, enabling the acquisition of reproducible data of renal interlobar vein impedance index (RIVI), defined as (Maximum flow velocity (MxV) – Minimum flow velocity)/MxV (Karabulut *et al.*, 2003; Gyselaers *et al.*, 2009b) and of hepatic pulse wave velocities (Gyselaers *et al.*, 2009a).

Despite methodologic standardisation, single measurements of RIVI showed poor intra-observer intraclass correlation (ICC) (Gyselaers *et al.*, 2008). Repeatability improved markedly after using the mean value of three consecutive measurements, as this resulted in good to excellent ICC both for RIVI (Gyselaers *et al.*, 2009b) and HV velocities (Gyselaers *et al.*, 2009a).

Figure 2A+B shows the intercostal two-dimensional ultrasound image at the craniocaudal mid-portion of the liver, and Figure 3A+B represents the transverse ultrasound section of the kidney at the level just above the renal hilus. Both figures illustrate the usefulness of color Doppler to distinguish different types of blood vessels in the parenchyma and to identify those veins in line with the direction of the Doppler beam in which velocimetry can be performed correctly (Lui *et al.*, 2005).

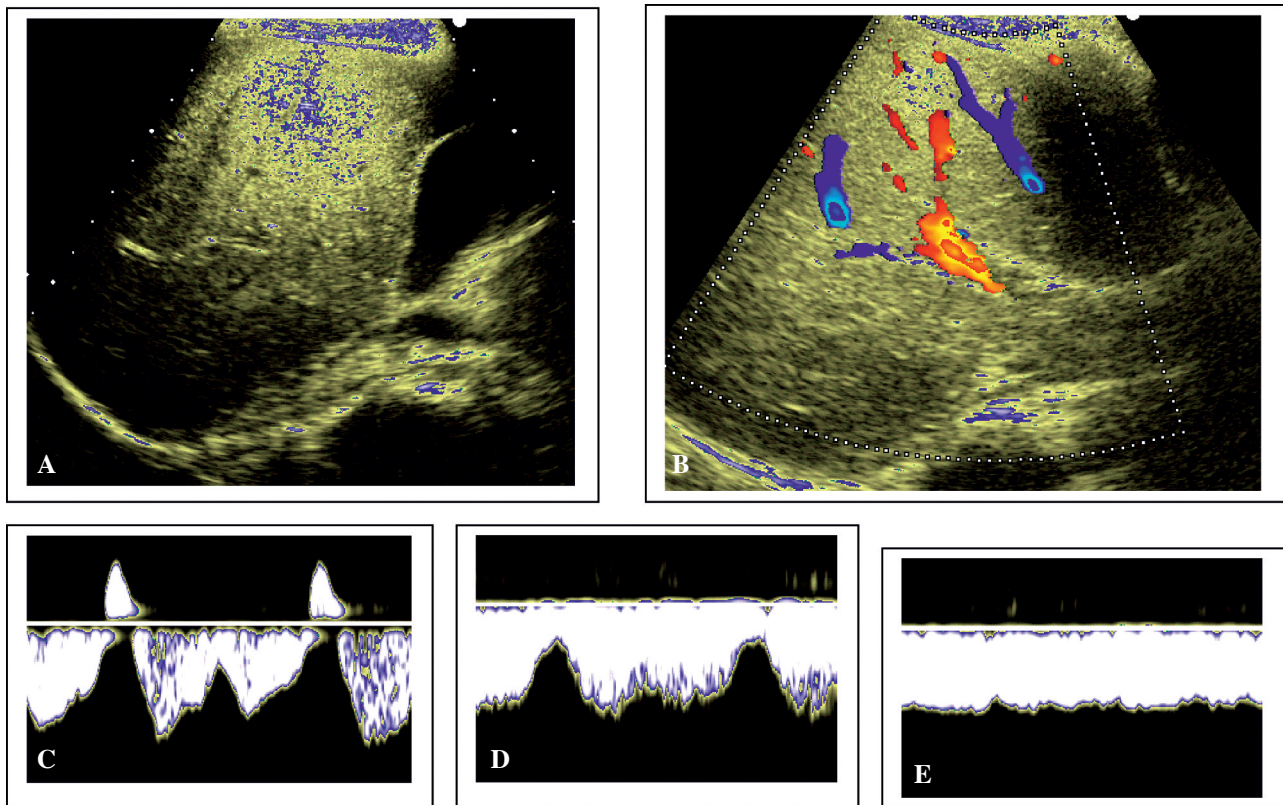


Fig. 2. — Illustrations of 2D-ultrasound and Doppler images of the intrahepatic vascular tree. Panel A shows the standard view of the liver, scanned intercostally at the craniocaudal midportion. Panel B shows the colour Doppler image at this level, which enables distinguishing portal branches and hepatic arteries (red) from hepatic veins (blue). Panel C illustrates the typical triphasic HV Doppler wave pattern, in which the A-deflection represents backflow of blood from the right atrium into the hepatic venous circulation during atrial contraction. This pattern is mostly observed in non-pregnant individuals and during early pregnancy. Panel B illustrates a biphasic pattern, where the A-deflection is not reversed. This pattern is commonly observed during midgestation. Panel E illustrates the flat HV pattern, which is the most common pattern in term pregnancy.

Doppler studies of lower central hemodynamics in non-pregnant individuals

As explained above, there are no anatomical valves between the central veins and the cardiac atria. Due to this open communication, the shape of the venous pulse and Doppler waves reflects the cardiac cycle of the right atrium (Berne and Levy, 2001a; Boulpaep, 2005b). This is well-known for the pulse-wave characteristics of the jugular veins (Boulpaep, 2005a), vena cava and hepatic veins (Downey, 2005). The typical pulse wave characteristics of hepatic veins are illustrated in Figure 2C. As is shown, the A-deflection represents central venous backflow away from the heart during atrial contraction (Gyselaers, 2008), the X-deflection represents forward flow towards the heart following atrial relaxation, which decelerates just before opening of the tricuspid valve (V-deflection). The Y-deflection represents forward flow following ventricular relaxation. Sometimes, a C-deflection is also present shortly after the A-deflection, and this represents the closure of the tricuspid valve. At increasing distance

from the heart, the triphasic shape of the venous pulse wave, presented in Fig. 2C, changes gradually towards a biphasic, monophasic and flat pattern. Biphasic venous pulse waves are the predominant pattern in renal interlobar veins of non-pregnant individuals (Fig. 3C). Monophasic waveforms are also observed frequently at the level of RIV (Fig. 3D) but they are not found in hepatic veins. A flat pulse wave is the common pattern observed in the lower extremities (Lewis, 2005), and is also frequently observed in RIV during ureteral obstructive disease (Fig. 3E) (Oktar *et al.*, 2004; Bateman and Cuganesan, 2002). The same types of Doppler waveforms are also found in the venous circulation of the fetus: triphasic patterns are observed at the level of the VCI and hepatic veins, biphasic waveforms are present in the ductus venosus and flat patterns are found in the umbilical vein (Hecher and Campbell 1996; Moll 1999).

As explained above, anatomical variations and intrahepatic shunts are responsible for a wide inter-individual variation in the presence of tri- or biphasic or flat Doppler waves in the liver of healthy

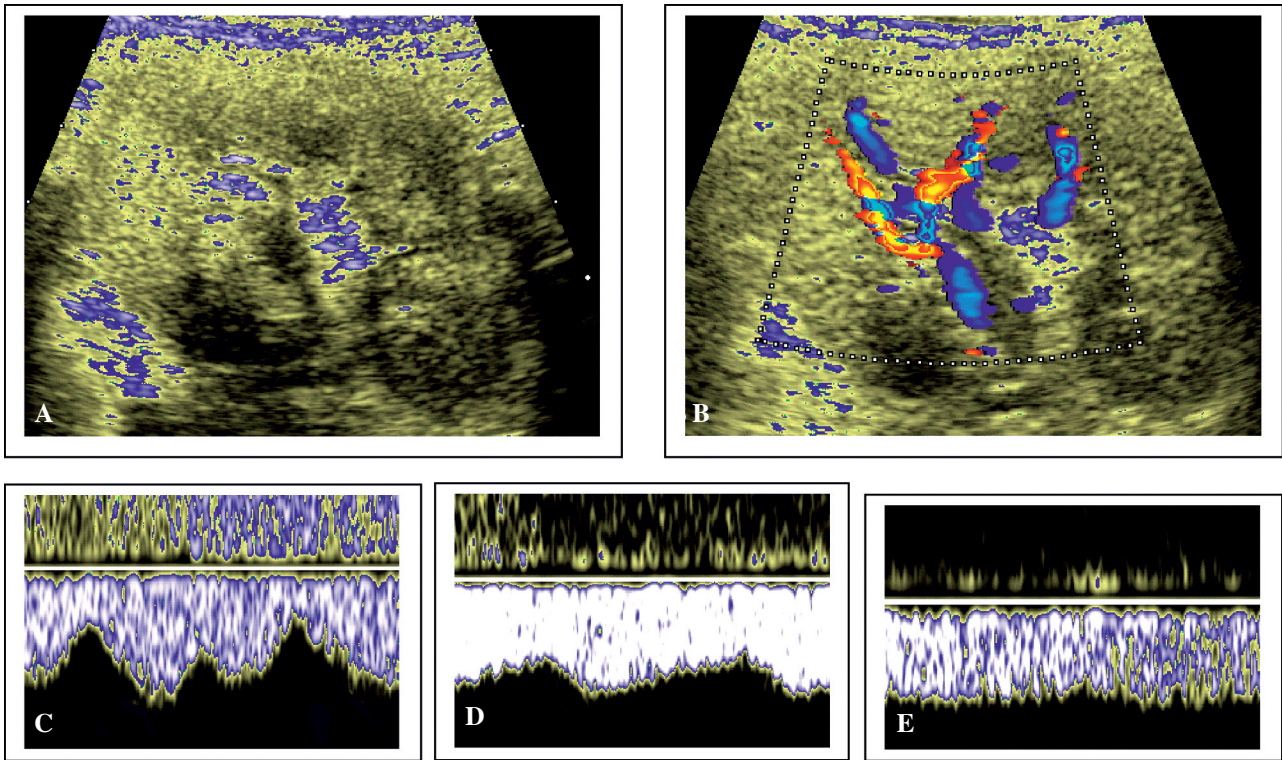


Fig. 3. — Illustrations of intrarenal vascularity, as observed by 2D- ultrasound and Duplex sonography. Panel A shows the standard view of the kidney, scanned in transverse position at the level just above the renal hilus. The intrarenal pyelon can be identified easily. The interlobar vessels are located between the pyelon and the renal cortex. Colour Doppler imaging, as illustrated in panel B, allows distinguishing interlobar arteries (red) from veins (blue). Panel C illustrates the typical biphasic pattern of renal interlobar veins, which is the most common pattern in non-pregnant individuals and during early and midgestation. Panel D shows the monophasic pattern, which is very common in term pregnancies. Panel E illustrates a flat pattern, which is frequently found during urological obstruction.

individuals (Pedersen *et al.*, 2005). Besides, these patterns are also strongly influenced by cardiac and liver diseases. Typical patterns of abnormal HV Doppler waveforms have been reported for restrictive and constrictive cardiopathy, pulmonary hypertension and tricuspid regurgitation (Oh *et al.*, 2007). These patterns also show typical variations with respiration. Similarly, an association was reported between mono- and biphasic HV Doppler waveform patterns and histology of liver steatosis (Schneider *et al.*, 2005; Colli *et al.*, 1994), whereas the presence of triphasic waves essentially excludes fatty infiltration of the liver (Schneider *et al.*, 2005; Dietrich *et al.*, 1998). Monophasic patterns in HV have also been reported for impaired liver function due to cirrhosis (Bolondi *et al.*, 1991), compression by intra-abdominal or intrahepatic masses (Ohta *et al.*, 1994) or HV thrombosis (Budd-Chiari Syndrome) (Bolondi *et al.*, 1991; Ohta *et al.*, 1994).

In non-pregnant individuals, Doppler studies of renal interlobar veins are used in obstructive uropathy to distinguish physiological from pathological pyelocaliectasis (Bateman and Cuganesan, 2002; Oktar *et al.*, 2004), for non-invasive monitoring of transplant kidneys (Salgado *et al.*, 2003; Zubarev

2001) and in the work-up of renal vein occlusion (Witz *et al.*, 1996; Zubarev 2001).

Doppler studies of hepatic veins during pregnancy

As illustrated in Figure 2 C-E, there is a high intra- and interindividual variation of HV Doppler waves, ranging between triphasic, biphasic and flat patterns (Downey, 2005; Pedersen *et al.*, 2005). Roobottom *et al.*, reported that during the course of normal pregnancy, the HV waveforms changed from predominantly triphasic to predominantly flat patterns (Roobottom *et al.*, 1995). The postpartum return from gestational patterns to the prepregnant condition has also been reported (Pekindil *et al.*, 1999). The Hepatic Vein A-deflection, known to represent central venous backflow during atrial contraction, was reported to convert to constantly forward moving flow into the direction of the heart at about 22-24 weeks of gestation (Gyselaers *et al.*, 2009a). This development with advancing pregnancy mimics the one in plasma volume (de Swiet, 1998). Therefore, it was suggested that this phenomenon resulted from dampening of the intermittent backflow during

the cardiac cycle by increasing intravascular filling (Gyselaers *et al.*, 2009a). Consecutive Doppler-derived estimates of hepatic flow in the course of pregnancy suggested a significant rise in hepatic perfusion relative to the non-pregnant state, by 28 weeks. Since hepatic arterial blood flow remains unchanged throughout pregnancy, this effect may reflect a rise in portal venous drainage after 28 weeks pregnancy (Nakai *et al.*, 2002).

Figure 4B shows the evolution of HV A-wave velocities, measured at 1-2 week intervals, between 9 weeks and term in an uneventful pregnancy. As is shown, the velocities change from positive towards the liver (triphasic waves) during early pregnancy, to negative into the direction of the heart (biphasic and flat waves) in the second trimester. In this particular case, the shift from tri- to biphasic and flat Doppler waves occurred at 25-27 weeks, but shortly returned to triphasic again by 32 weeks, and then became biphasic and flat again until term. This reversal illustrates the high intra-individual variation of HV waveforms during the third trimester of pregnancy. In a group of 13 uncomplicated pregnancies, 3 different types of HV Doppler wave combinations could be identified in the course of the third trimester of pregnancy: (1) women presenting flat waveforms only, (2) women having both flat and biphasic waveforms, and (3) women presenting flat, bi- and triphasic waveforms (Gyselaers *et al.*, 2009a).

Doppler studies of renal interlobar veins during pregnancy

As illustrated in Figure 3 C-D, Doppler wave patterns in RIV of pregnant women gradually shift from biphasic to monophasic in the course of pregnancy (Gyselaers *et al.*, 2009b; Gyselaers *et al.*, 2008). Karabulut *et al.* were the first to report lower RIVI values in pregnant women compared to non-pregnant individuals (Karabulut *et al.*, 2003). From the late second trimester onward, they observed that at the right side, RIVI was 10-15% lower than at the left side, and this difference was inversely related to the diameter of the renal pelvis. This observation was considered to result from increased intrarenal interstitial pressure, due to retroperitoneal compression by the growing pregnant uterus with subsequent dilatation of the renal pelvis, especially on the right side (Gyselaers *et al.*, 2008; Karabulut *et al.*, 2003). Sometimes, this can be associated with the presence of flattened RIV Doppler waveforms (fig 3E). As mentioned above, flat RIV Doppler wave patterns are frequently observed during obstructive uropathy (Bateman and Cuganesan, 2002; Oktar *et al.*, 2004).

In a cross-sectional study (Gyselaers *et al.*, 2008) and in a prospective observational study (Gyselaers

et al., 2009b), RIVI was found to decrease gradually in both kidneys during the first and second trimester of pregnancy, with only an ongoing decline until 30 weeks at the right side. The change in RIV Maximum and Minimum flow velocities with advancing pregnancy mimicked the changes with pregnancy in Cardiac Stroke Volume and Renal Glomerular Filtration (Gyselaers *et al.*, 2009b), suggesting an association with features of maternal gestational cardiac and renal adaptations. Venous flow velocities were consistently higher in the right than in the left kidney, and this was linked to interrenal anatomical differences: as detailed previously, larger diameters and more accessory renal veins are present on the right side (Satyapal, 1995; Satyapal *et al.*, 1995b; Satyapal *et al.*, 1995a), greatly facilitating venous drainage. Influx of ovarian blood and compression between Superior Mesenteric Artery and Aorta are likely to reduce flow velocities in the left renal vein (Ahmed *et al.*, 2006; Itoh *et al.*, 1997). These anatomical differences also help to explain the lower RIVI values during the third trimester of pregnancy (Gyselaers *et al.*, 2009b).

There appears to be a variation in time for RIVI values in both kidneys. The graphic presentation of serial RIVI measurements at weekly or two-weekly intervals shows a slow oscillating pattern, as illustrated in Figures 4A and 5A+B. The frequency and amplitude of this sinusoidal pattern seems similar in both kidneys but the increasing and decreasing slopes do not occur simultaneously. Figure 4A shows that this oscillating pattern is present both in a normal menstrual cycle as throughout pregnancy. Figure 5b illustrates a case of reduced oscillation during the third trimester of pregnancy, particularly on the right side where RIVI values are lower than on the left side (Gyselaers *et al.*, 2008). This oscillating pattern suggests that the venous vascular wall activity towards maintenance of venous tone and/or distensibility is a dynamic physiologic process which is variable in location and time.

Towards a link between maternal venous Doppler parameters and known features of gestational cardiovascular physiology

Human pregnancy is subject to major adaptations of the maternal cardiovascular system (Duvekot and Peeters, 1994; de Swiet, 1998). These adaptations occur on both the arterial and venous sites of the circulation. Total peripheral resistance decreases to a nadir at midgestation, and increases again in the third trimester. As a result, arterial blood pressure is lower in the second trimester than in early or late gestation, and venous distensibility is increased (Sakai *et al.*, 1994). Plasma volume expands to a maximum in the

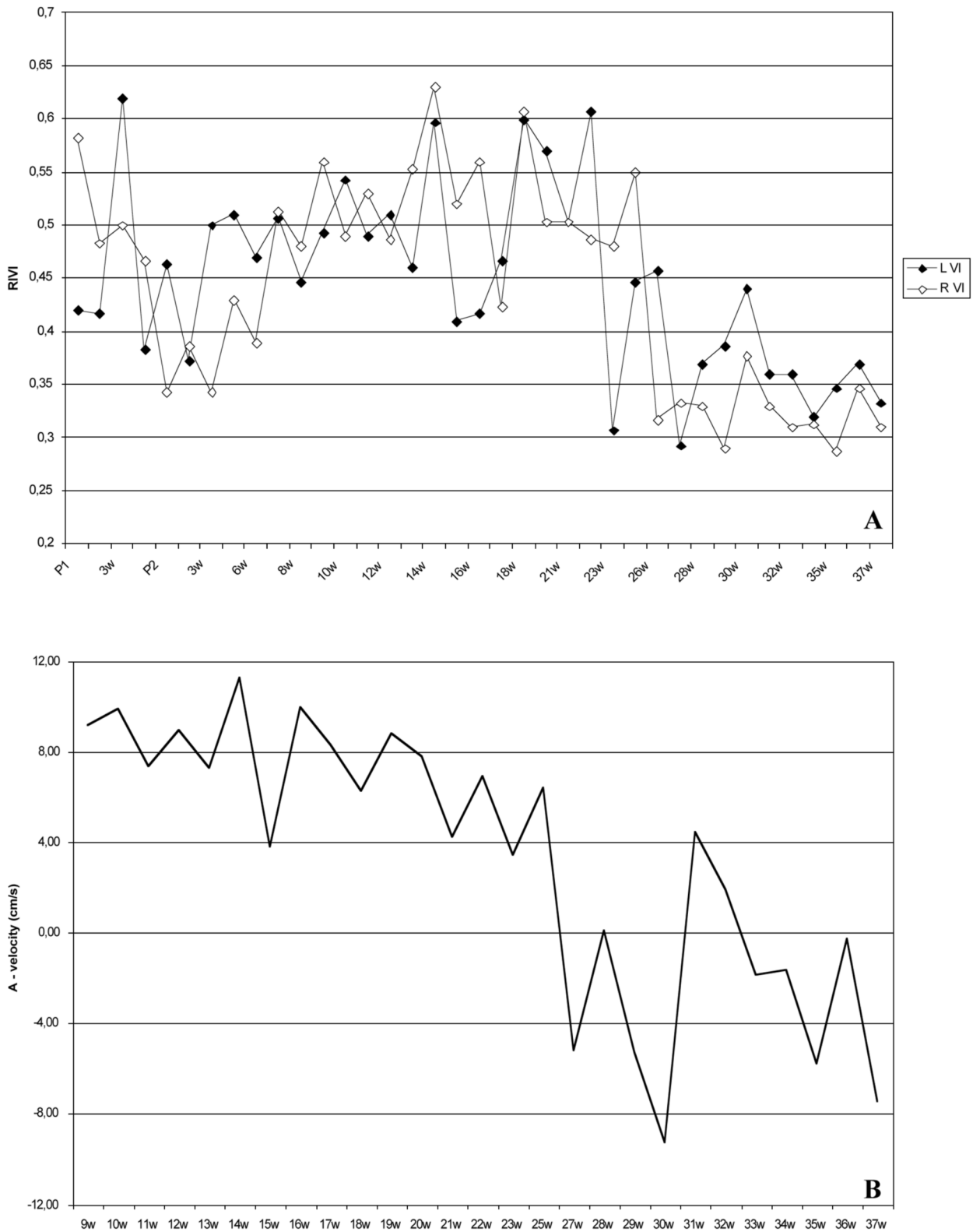


Fig. 4. — Graphical illustration of serial measurements of Renal Interlobar Vein Impedance Index (RIVI) (upper panel) and Hepatic Vein A (HVA) velocity (lower panel) at 2-weeks interval from preconception (A) or early pregnancy (B) until term. As is shown, RIVI measurements of both kidneys show a slow pattern of oscillation with the highest values intermittently observed in the left or right kidney. This oscillation is present both during the normal menstrual cycle, marked as the interval between menstrual period 1 (P1) and menstrual period 2 (P2), as during pregnancy (3 to 37 w). In the course of pregnancy, RIVI decreases and at term, right renal RIVI values are lower than those from the left kidney. This is presented more clearly in Figure 5. Simultaneously, HVA-velocities shift from positive values, reflecting triphasic HV Doppler wave patterns with blood flowing into the direction of the liver during atrial contraction, to negative values, representing biphasic or flat HV Doppler wave patterns with blood flowing into direction of the heart. In this woman, the conversion from backward to forward flow relative to the heart occurs around 26 weeks. She also shows a transient reversal to positive HVA-values, at 32 weeks, which become negative again afterwards. The latter illustrates the intra-individual variation of HV Doppler wave patterns during uneventful third trimester pregnancy.

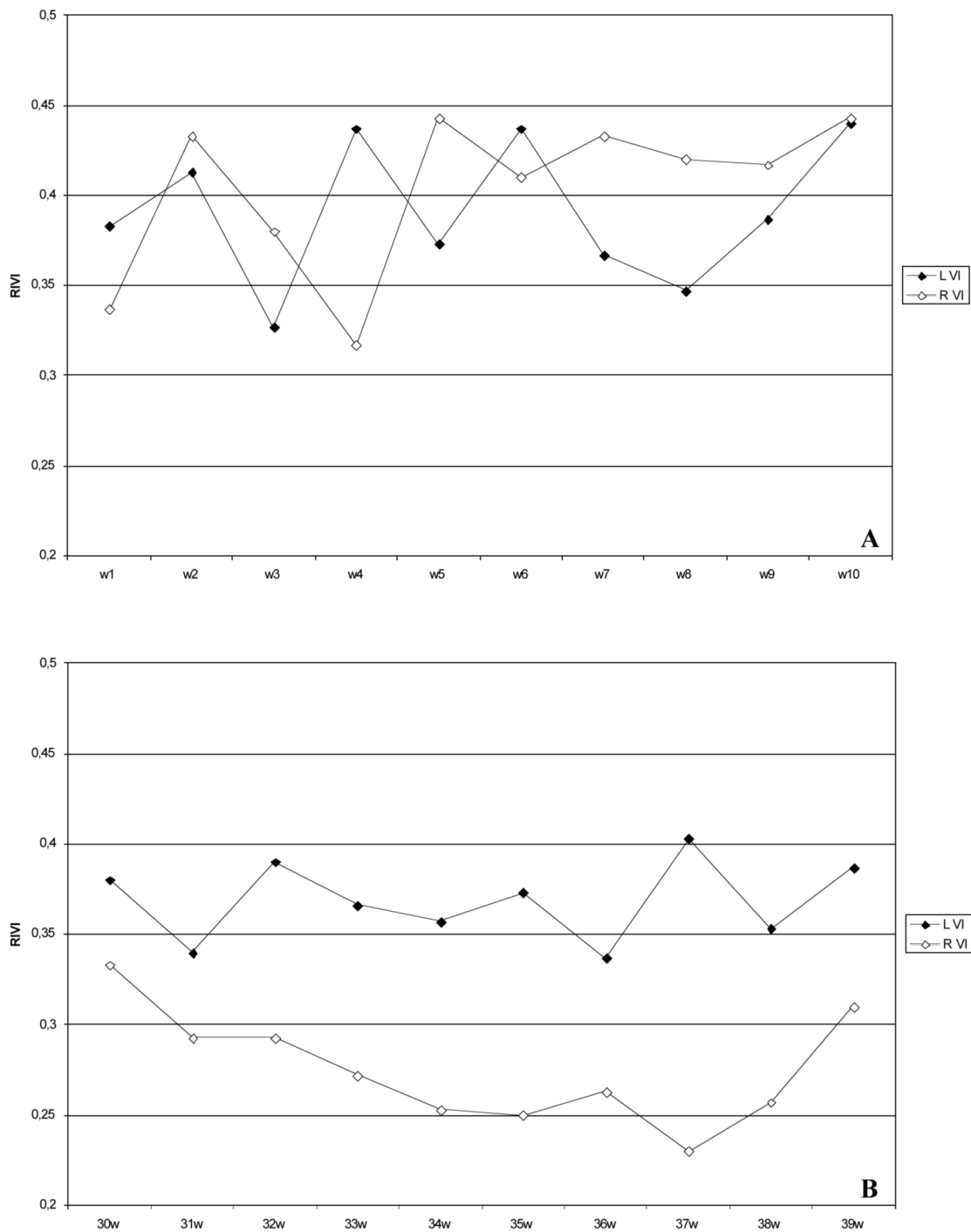


Fig. 5. — Illustration of serial measurements of Renal Interlobar Vein (RIV) Impedance Index (RIVI) at weekly intervals in a non-pregnant individual (upper panel), and during uncomplicated third trimester pregnancy (lower panel). During the third trimester of pregnancy, right RIVI values are consistently lower than those at the left kidney, and the pattern of oscillation, as illustrated in figure 4, seems to be less pronounced than in the non-pregnant woman.

early third trimester and reduces slightly afterwards. These changes co-exist with a gradual increase of maternal heart rate throughout pregnancy, an increase of cardiac stroke volume until a maximum at midgestation and an increase of cardiac output to approximately 50% above the prepregnant level at term (Duvekot and Peeters, 1994; de Swiet, 1998).

Most Doppler studies on gestational haemodynamics focus either on the analysis of maternal uterine artery waveforms or on the evaluation of the fetal and uteroplacental circulations; the wide range of publications on these topics have been reviewed extensively (Abramowicz and Sheiner, 2008; Papageorghiou and Leslie, 2007; Cnossen *et al.*,

2008). However, Doppler studies on maternal venous haemodynamics are scarce.

As explained above, the venous tone and with it, the venous compliance are crucial determinants of cardiac output by their direct impact on central venous pressure and cardiac preload, with the latter regulating stroke volume by way of the Frank-Starling mechanism (Boulpaep, 2005a). Venous compliance, which is much larger than arterial compliance (Wang *et al.*, 2006), decreases with age, and is influenced by autonomic function, medication, systemic and/or vascular diseases (Pang, 2001), and parity (Dhawan *et al.*, 2005; Hohmann *et al.*, 1996). During uneventful pregnancy, venous compliance and distensibility are raised (Sakai *et al.*, 1994) returning to nonpregnant values in the first 3 months postpartum (Skudder, Jr. *et al.*, 1990). The ability of vessel walls to contract or relax and, as such, modulate compliance can be studied by Duplex sonography: maximum (MxV) and minimum (MnV) flow velocities are measured to calculate venous impedance index, which is the venous equivalent of arterial resistivity index (RI), defined as $(MxV - MnV) / MxV$ (Bateman and Cuganesan, 2002). Renal Interlobar Vein impedance index (RIVI) decreases with advancing pregnancy, which is consistent with an increase in venous compliance (Karabulut *et al.*, 2003; Gyselaers *et al.*, 2008; Gyselaers *et al.*, 2009b). This observation supports the view that Duplex sonography enables indirectly to generate noninvasive information on venous compliance and distensibility, with the RIVI measurement providing more or less quantitative information on tone and with it, resistance in the renal interlobar veins. In this perspective, the undulating pattern of RIVI values in non-pregnant and pregnant women, illustrated in figures 4 and 5, is interesting. The pattern suggests that the physiologic process of maintaining venous tone requires a dynamic mechanism which enables achieving a fairly constant steady state, but in the mean time this mechanism is highly variable at different sites of the venous bed. The splanchnic venous bed plays a critical role in the homeostatic responses to changes in the intravascular volume (Dhawan *et al.*, 2005). Up to 33% of the total blood volume resides here, with 1/3 located in the liver (Pang 2001; Berne and Levy, 2001b). Therefore, the splanchnic veins are called capacitance vessels (Pang, 2000; Pang, 2001). Sympathetic nerve stimulation can mobilise up to 21% of the total blood volume into the circulation (Pang, 2001), thus raising venous return markedly (Tyberg, 2002). Again, the contribution of the liver in this process is important (Pang, 2001). During pregnancy, the properties of the vascular walls of mesenteric veins change allowing the accommodation of a larger intravascular volume at the expense of compliance

(Hohmann *et al.*, 1996). Doppler-derived estimations of hepatic flow during pregnancy have shown that hepatic perfusion increases significantly after 28 weeks most likely in conjunction with a rise in portal drainage (Nakai *et al.*, 2002). This development is associated with dampening of the HV A-wave, indicating that during the second trimester of pregnancy the normal physiologic backflow of right atrial blood during atrial contraction into the VCI and hepatic venous bed, reverses to constant forward moving flow towards the heart (Gyselaers *et al.*, 2009a). The pattern of change in HV A-velocities with advancing pregnancy mimics the one in plasma volume (Gyselaers *et al.*, 2009a). Therefore, the presence or absence of the HV A-wave (Gyselaers *et al.*, 2009a), together with the manifestation of tri- or biphasic and flat HV Doppler wave patterns (Fig. 2A-C), provide indirect information on the hepatic venous filling state. In this context, the large intra-individual variation in types of HV Doppler waves during the third trimester of pregnancy is another interesting observation (Gyselaers *et al.*, 2009a). This suggests that the liver may be actively involved in the preservation of the circulating volume during the third trimester of pregnancy.

These observations are the basic elements of an interesting hypothesis, in which an active role is attributed to the maternal venous compartment in the regulation and maintenance of the pregnant woman's circulating volume, which is known to be crucial for a normal course and outcome of pregnancy.

Relevance of exploring maternal venous hemodynamics by Duplex sonography

From the information summarised in this review, it is clear that data from Duplex sonography studies into maternal venous hemodynamics add to the current knowledge of the normal function and adaptation of the venous compartment during pregnancy. Next to this, several papers have been published reporting abnormalities of venous Doppler parameters at the level of renal interlobar or hepatic veins during preeclampsia (Bateman *et al.*, 2004; Gyselaers *et al.*, 2009b; Gyselaers *et al.*, 2009a). Increased RIVI values and intrahepatic backflow during atrial contraction are more pronounced in early- than in late-onset preeclampsia (Gyselaers *et al.*, 2009b; Gyselaers *et al.*, 2009a). Even more, in early- but not in late-onset preeclampsia, renal interlobar venous Doppler abnormalities were observed simultaneously in both kidneys and presented up to several weeks before clinical onset of disease (Gyselaers and Mesens, 2009). These studies illustrate that the venous compartment is actively involved in preeclampsia-related maternal cardiovascular maladaptation and

that its assessment may provide relevant information on some pathophysiologic background mechanisms of gestational hypertensive disease and/or clinical work-up of preeclampsia. This particular topic is the subject of another review paper currently in progress.

Conclusion

The present review of the literature provides extensive evidence for the feasibility of obtaining information on the maternal venous compartment by Duplex ultrasonography. The reported results correlate well with known features of gestational cardiovascular physiology. Some of the observations open perspectives to generate and test new hypotheses on the physiologic role of the venous compartment in the volume homeostasis during pregnancy. Finally, the resemblance of the maternal and fetal venous circulations (Kiserud, 2000; Kiserud, 2005) suggests that a better insight into dynamic events in the maternal venous circulation may also contribute to a better understanding of fetal venous haemodynamics. Last but not least, ultrasonography is generally accepted as being safe in pregnancy, and it is an examination easily accessible to all pregnant women undergoing obstetric scanning. These arguments are an open invitation for obstetric ultrasonographers to initiate Doppler studies in the “forgotten field” of obstetrics: the maternal venous compartment.

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