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(2015) Maternal venous Doppler characteristics are abnormal in pre-eclampsia but
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GYNECOLOGY, 45 (4), p. 421-426.

DOI: 10.1002/uog.13427

Handle: <http://hdl.handle.net/1942/18858>



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Gyselaers, Wilfried; Staelens, Anneleen; Mesens, Tinne; Tomsin, Kathleen; Oben, Jolien; Vonck, Sharona; Verresen, Luc & Molenberghs, Geert(2015) Maternal venous Doppler characteristics are abnormal in pre-eclampsia but not in gestational hypertension. In: ULTRASOUND IN OBSTETRICS & GYNECOLOGY, 45 (4), p. 421-426

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**Maternal venous Doppler characteristics are abnormal in preeclampsia but
not in gestational hypertension.**

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This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/uog.13427

Abstract

Aims: To compare functional characteristics of thoraco-abdominal arteries and veins in proteinuric and non-proteinuric hypertension in pregnancy.

Material and methods: This retrospective study includes singleton pregnancies of women during uncomplicated third trimester (UP), with non-proteinuric gestational hypertension (GH), with early-onset preeclampsia (PE) diagnosed < 34 weeks (EPE) or with late-onset PE \geq 34 weeks (LPE). Demographic maternal and neonatal data were recorded together with maternal serum and urine analytes. All women had standardised automated blood pressure measurement, together with non-invasive Impedance Cardiography (ICG) for measurement of cardiac output (CO), aorta flow velocity (VI) and acceleration (ACI). A standardised combined Doppler – ECG assessment of maternal venous hemodynamics was done for measurement of Renal Interlobar Vein Impedance Index (RIVI), Hepatic Vein Impedance Index (HVI) and venous pulse transit time (VPTT) in liver and kidneys. Finally, resistivity index (RI), pulsatility index (PI) and arterial pulse transit time (APTT) were measured at the uterine arcuate arteries. SPSS software Version 20.0 was used for statistical comparison at nominal level $\alpha = 0.05$, using a non-parametric Mann-Whitney U-tests for intergroup comparison of continuous data and Fisher's exact tests for categorical data. Significant linear dependence between clinical, laboratory, ICG and Doppler-ECG variables was identified using Pearson's correlation coefficient (PCC) at nominal level $\alpha=0.05$ (two-tailed), and coefficient of determination R^2 and corresponding p-value were calculated.

Results: A total of 150 pregnancies were evaluated: 22 UP, 41 GH, 31 EPE and 56 LPE. Aorta VI and ACI were lower in GH, EPE and LPE than in UP. Both EPE and LPE differed from GH by shorter APTT at uterine arcuate arteries and higher RIVI and HVI.

Hemodynamic abnormalities were most pronounced in EPE, where uterine arcuate artery RI was higher and VPTT in kidneys and liver were shorter than in LPE. There was a relevant coefficient of determination between degree of proteinuria and RIVI for left ($R^2 = 0.145$) and right kidney ($R^2 = 0.120$) in LPE, which was not true for EPE.

Conclusion: There is a gradual aggravation of arterial and venous hemodynamic abnormalities from GH to LPE and finally EPE. Venous hemodynamic abnormalities are only present in preeclampsia, with a linear correlation between proteinuria and RIVI in LPE. The role of the maternal venous compartment in the pathophysiology and etiology of PE-related symptoms may be much more important than considered today.

Introduction

Normal circulation of the blood requires the coordinated activity of several systems in the cardiovascular circuit: the heart, the arterial compartment, the microcirculation, the venous compartment and the blood. Cardiovascular profiling is defined as the evaluation of the functionality of these systems for categorisation of the cardiovascular system into functional subtypes^{1,2}. For this, invasive and non-invasive methods can be used^{3,4}. Cardiovascular profiling in pregnant women can be performed non-invasively using standardized combined Doppler-electrocardiography (D-ECG) assessment⁵ and Impedance Cardiography (ICG)^{6,7}.

Cardiovascular dysfunction has been reported as less severe in gestational hypertension than in preeclampsia⁸⁻¹⁰ and pharmacologic response was found to differ between both entities⁸. Similarly, cardiac, arterial and venous hemodynamic dysfunction was found to present less severe in late-onset than in early-onset preeclampsia¹¹⁻¹³, and maternal serum concentrations

of angiogenic factor differed between both entities ¹⁴. Micro-circulatory changes were also reported to differ between preeclampsia and HELLP-syndrome ¹⁵.

In this paper, we report our observations on the non-invasive maternal cardiovascular profile with D-ECG and ICG in women with different clinical types of hypertension in pregnancy, relative to the findings in uncomplicated pregnancies (UP): gestational hypertension (GH), early-onset preeclampsia (EPE) and late-onset preeclampsia (LPE).

Materials and methods

Approval of the ethical committee was obtained before study onset (MEC ZOL reference: 08/049, 09/050 and 10/065).

Women, admitted between 1/10/2009 and 31/12/2013 to the Fetal Maternal Medicine Unit of Ziekenhuis Oost Limburg Genk Belgium for hypertension in pregnancy were included. Exclusions were women with multiple gestation, essential hypertension with or without superimposed preeclampsia, renal disease with or without proteinuria, history of organ transplantation, women with concomitant diseases as diabetes, thyroid dysfunction, autoimmune disease, cholestasis or liver disease, women with HELLP syndrome, women with thrombocytopenia or with non-hypertensive proteinuria and IUGR without associated maternal symptoms. Included were only those women without known diseases and new onset hypertension > 20 weeks (Fig 1). In addition to this, a group of women with normal maternal and neonatal outcome at birth, who were admitted to the antenatal unit for presumed hypertension in the third trimester of pregnancy, were used as a control group. PE was defined as new onset gestational hypertension ($\geq 140/90$ mmHg on at least 2 occasions at least 6 hours apart) with de novo proteinuria (≥ 300 mg/24hours) without thrombocytopenia or liver dysfunction, according to the criteria of the National High Blood Pressure Education Program Working Group ^{16,17}. New onset hypertension > 20 weeks with proteinuria < 300

mg/24h is defined as gestational hypertension (GH). PE < 34 weeks is defined as early onset preeclampsia (EPE), whereas PE \geq 34 weeks is defined as late onset preeclampsia (LPE). As such, there were 4 categories eligible for retrospective analysis: uncomplicated pregnancies (UP), gestational hypertension without proteinuria (GH), early onset preeclampsia (EP) and late onset preeclampsia (LP).

For each woman, data on demographics and perinatal outcome were recorded, together with results from serum and urine biochemistry, ICG-measurements and maternal Doppler-ECG parameters. Maternal demographic data include age (years), body mass index (BMI) at first visit as recorded from the records, gestational age at assessment (weeks), parity and use of antihypertensive medication. Data on perinatal outcome comprise gestational age at delivery (weeks), birth weight (BW in g) and customized birth weight percentile (BW% in %). Serum parameters include thrombocytes (1000/ μ L), creatinine (μ mol/L), aspartate aminotransferase (ASAT in U/L), alanine aminotransferase (ALAT in U/L), and uric acid (μ mol/L). Parameters evaluated in 24 hour urine collections at the time of diagnosis of PE were creatinine clearance (mL/min), and proteinuria over 24 hours (mg).

At the same time point, all women had an Impedance Cardiography (ICG-) assessment together with a combined Doppler-ECG (D-ECG-) evaluation at different sites of the circulation, as illustrated in Figure 2. None of the subjects were in labour at the time of the investigations.

ICG- examinations were performed in standing position using the Non-Invasive Continuous Cardiac Output Monitor (NICCOMO[®], Software version 2.0, Medis Medizinische Messtechnik GmbH, Ilmenau Germany) according to the reported methodology and protocol with known repeatability ⁶. This impedance technique is a non-invasive method of evaluating haemodynamic parameters, based on thoracic resistance changes of a high frequent, low

powered electrical current, measured during each heart cycle using a set of 4 skin-electrodes^{18,19}. Blood pressures were measured standardised using the automated device of the NICCOMO-monitor. Pressure parameters were systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse pressure ($PP = SBP - DBP$) and mean blood pressure ($MBP = DBP + PP/3$), all expressed in mmHg. ICG-parameters were left ventricular output parameters, aortic flow parameters, and thoracic fluid content (TFC in 1/kOhm)^{6,18}. Left ventricular output parameters were stroke volume (SV) in mL, heart rate (HR) in beats/min and cardiac output in mL/min ($CO = HR \times SV$). Aortic flow parameters were velocity index (VI in 1/1000/s) which is equivalent to the amplitude of the systolic wave and acceleration index (ACI in 1/100/s²) which stands for the maximum acceleration of blood flow in the aorta^{6,18}. Thoracic fluid content is measured directly from the electrical conductivity of the chest and reflects the total of intracellular, interstitial and circulation fluid volumes in the thorax^{6,18}.

All Doppler-ECG examinations were done by 5 sonographers (WG, TM, AS, KT and SV) according to the protocol reported elsewhere^{20,21}, with known intra - and interobserver correlation²². All women had ECG-D investigations in supine position at the level of hepatic veins (HV), renal interlobar veins (RIV) of both kidneys, and left and right arcuate uterine arteries as reported²⁰. Uterine arcuate arteries were preferred over uterine arteries for their intra-parenchymatous localization, comparable with the localization of hepatic and renal interlobar veins²³, and were performed within a maximum of 2 cm distance from the bifurcation at the uterine artery. Arterial pulsatility and resistivity index were measured, defined as $[(\text{maximum velocity (MxV)} - \text{minimum velocity (MnV)})/\text{mean velocity}]$ and $[\text{MxV} - \text{MnV}]/\text{MxV}$ respectively. Doppler parameters measured at the level of HV and RIV were MxV and MnV. From this, Hepatic Vein velocity index (HVI) and Renal Interlobar Vein Impedance Index (RIVI) were calculated as $[(\text{MxV}-\text{MnV})/\text{MxV}]$ ^{20,24}. Pulse transit times were measured as the time interval between corresponding characteristics of the cardiac

cycle of the ECG-signal and Doppler wave. Arterial pulse transit time (APTT) was defined as the time interval (ms) between the maternal ECG Q-wave and start of Doppler systole, corrected for the duration of the corresponding cardiac cycle²³. Venous pulse transit times (VPTT) were defined as the time interval (ms) between the maternal ECG P-wave and corresponding Doppler A-wave, again corrected for the duration of the corresponding cardiac cycle²⁵.

Data are presented as medians with first and third quartiles, or as percentages. SPSS software Version 20.0 was used for statistical comparison at nominal level $\alpha = 0.05$, using a non-parametric Mann-Whitney U-tests for intergroup comparison of continuous data and Fisher's exact tests for categorical data. Significant linear dependence between clinical, laboratory, ICG and ECG-Doppler variables was identified using Pearson's correlation coefficient (PCC) at nominal level $\alpha=0.05$ (two-tailed), and goodness-of-fit of the resulting linear regression model with heteroskedastic variance was reported by coefficient of determination R^2 and corresponding p-value (SAS software V9.2).

Results

A total of 150 women were included: 22 had UP, 41 had GH, 31 had EPE and 56 had LPE. Inclusions and exclusions in this study from the total cohort of women, admitted to the hospital for hypertension in pregnancy during the study period, are presented in Figure 1.

Demographic data are presented in Table 1, together with results from maternal serum and urine laboratory tests.

Table 2 shows the blood pressure values and ICG measurements of cardiac output, aortic flow velocities and thoracic fluid content. As is shown, HR, SV or CO were not different between groups. For GH, LPE and EPE, aortic flow VI and ACI were lower than in UP.

Table 3 presents the D-ECG results as measured at the level of hepatic veins, renal interlobar veins and uterine arcuate arteries. Only in preeclampsia, venous impedance index and arterial pulse transit times were different from UP. Arterial resistivity and pulsatility index and venous pulse transit times were different from UP only in EPE. Interestingly in late-onset preeclampsia, left and right kidney RIVI correlated with degree of proteinuria: PCC for the left kidney was 0.381 ($p=0.004$, $R^2 = 0.145$) and PCC for the right kidney was 0.347 ($p=0.010$, $R^2 = 0.120$). These correlations correspond to regression-based predictions as $\text{proteinuria} = 9E2+5.29E3 \times \text{Left RIVI}$ and $\text{Proteinuria} = 4.58E2+4.41E3 \times \text{Right RIVI}$. No correlation was found between proteinuria and RIVI in early-onset preeclampsia: PCC for the left kidney was 0.073 ($p=0.696$, $R^2 = 0.005$) and PCC for the right kidney was 0.234 ($p=0.214$, $R^2 = 0.055$).

The most important findings of Tables 2 and 3 are summarized in Table 4. As compared to UP, hemodynamic dysfunction aggravates from GH to LPE and finally EPE.

Discussion

The data presented in this report support the view that (1) central arterial hemodynamic dysfunction is present in both gestational hypertension and preeclampsia, and (2) preeclampsia presents with signs of venous hemodynamic dysfunction, which is not true for gestation induced hypertension.

Our study is original because it evaluates aspects of hemodynamics at different sites of the maternal circulation: central and peripheral arterial hemodynamics together with venous hemodynamics. The strengths of our study are that every woman is examined according to a standard protocol using non-invasive assessment techniques with known inter- and intra-observer correlation^{6,18,22}. Next to this, the patients included in each group strictly comply with all reported criteria for each disorder, and are free of interfering maternal or gestational

diseases known at time of inclusion. The lack of a physiologic explanation for the true nature of the venous impedance index as a venous Doppler flow characteristic, as well as the lack of associative data on experimental measurements of central venous pressure and venous vascular tone in preeclampsia, are a limitation to our study. Next to this, our observational study is retrospective in nature, which does not allow drawing conclusions on cause and effect relationships or on the individual role of heart, arteries and veins in the development or the clinical presentation of PE. For this, a prospective clinical study in a large group of women and experimental data are needed.

Our data are consistent with the observations from others, reporting a gradation in hemodynamic dysfunction and severity of clinical presentation between subtypes of gestational hypertensive diseases, with EPE as the most severe subtype⁸⁻¹¹. Next to this, our observations are also in line with the ICG-measurements in pregnant hypertensive women as reported by Parrish et al²⁶, illustrating central arterial hemodynamic dysfunction and increased thoracic fluid content in the most severe subtypes of PE.

Next to this, our data in Table 3 illustrate that maternal venous hemodynamic dysfunction is a feature of both early- and late-onset preeclampsia, but not GH. Venous hemodynamic dysfunction in PE was reported for the first time by Bateman et al²⁷. In former publications, we have reported that RIVI is higher in EPE than in LPE¹³ and that HVI is also increased in PE, as compared to UP²¹. The higher values of RIVI in EPE than in LPE were linked to the presence of the so-called Doppler wave venous pre-acceleration nadir (VPAN)^{5,13}. VPAN results from the retrograde intravenous rebound of right atrial contraction, which in PE presents up to the level of the kidneys resulting in a more pronounced deceleration of blood flow and higher RIVI-values. It is unclear whether this rebound in PE relates to increased cardiac diastolic dysfunction² or to reduced venous distensibility²⁸. Pulse transit time is considered a measure for vascular stiffness: in conditions of increased vascular tone or

stiffness, the propulsion wave is transported faster through the circulation than in conditions of low vascular tone, and this is responsible for a shorter time interval between ECG and pulse or Doppler wave ²⁹⁻³¹. During PE, shorter pulse transit times have been measured at both the arterial ³² and venous sites of the circulation ²³. It is likely that increased venous tone in PE is associated with a faster and more distant rebound of atrial contraction throughout the venous circulation, up to the level of the kidneys. As such, increased RIVI, with or without VPAN, can be considered a reflection of pulsatile counteraction of forward venous flow from the kidneys, which intermittently counteracts renal outflow during each atrial contraction ³³. Our observations of increased Doppler Impedance Index and shortened venous pulse transit times in intrarenal veins are compatible with a state of increased intravenous or intravenular hydrostatic pressure. Therefore, we propose renal venous congestion as an additional explanation for some of the clinical manifestations of PE. A decrease of venous outflow from the kidneys will result in a decrease of glomerular plasma flow and glomerular filtration rate. In order to maintain the glomerular filtration rate, local renin angiotensin aldosterone system (RAAS) will be activated by stimulation of the juxtaglomerular apparatus ³⁴. This intrarenal production of angiotensin II (Ang II) will result in proteinuria ³⁵ and increased salt sensitivity with subsequent edema and hypertension ³⁶. In PE circulating RAAS remains suppressed or unchanged ³⁷. Upregulation of Ang II Receptor-1 and increase of Ang II Receptor-1 Auto-Antibody in PE might further enhance the Ang II sensitivity ³⁸. Raised Ang II levels can cause proteinuria by several mechanisms: increased glomerular pressure, endothelial cell dysfunction, contraction of the podocytes and reduced expression of nephrin ³⁹. Experimentally induced increase of intravenous pressure in the renal veins ⁴⁰ or subobstruction to venous drainage from the kidneys has been shown to result in overt proteinuria, partially reversible by Ang II antagonism ³⁵. Proteinuria due to renal congestion has also been described in the nutcracker syndrome where the left renal vein is narrowed in

the angle between the aorta abdominalis and the arteria mesenterica superior, leading to orthostatic proteinuria mainly in young adults. The improvement of this type of proteinuria by ACE inhibition demonstrates an etiologic role for Ang II ⁴¹. The correlation we found between RIVI and degree of proteinuria in LPE suggests a possible underrecognised role for venous hemodynamics in the pathophysiology of PE, and invites for more research into the pathophysiology of PE-related proteinuria.

Conclusion

The combination of our observations allow describing the cardiovascular profile for different types of hypertensive disease in pregnancy : (1) gestational hypertension combines increased blood pressures with central hemodynamic dysfunction, and (2) preeclampsia presents as gestational hypertension with venous hemodynamic dysfunction.

Acknowledgements

This study is part of the Limburg Clinical Research Program (LCRP) UHasselt-ZOL-Jessa, supported by the foundation Limburg Sterk Merk, Hasselt University, Ziekenhuis Oost Limburg and Jessa Ziekenhuis.

Disclosure of Interests

The authors report no conflict of interest.

Table 1: Maternal demographics, neonatal outcome and laboratory results.

| | UP n=22 | GH n=41 | LPE n=56 | EPE n=31 |
|--------------------------------------|-------------------------------|-----------------------------|----------------------------|-------------------------------|
| Maternal age (y) | 29.00 (24.75;31.25) | 30.00 (26.00;32.50) | 28.00 (25.25;30.75) | 29.00 (26.00;30.00) |
| Start BMI | 25.06 (20.11;28.48) | 25.90 (22.72;30.02) | 25.08 (23.22;28.64) | 24.48 (21.80;28.81) |
| Nulliparity n (%) | 11 (50%) \$ | 28 (68.3%) Q | 47 (83.9%) * | 22 (71.0%) ° |
| Medication n (%) | 0 (0%) | 3 (7.3%) | 5 (8.93%) | 3 (9.68%) |
| GA examination (w) | 36.79 (34.11;39.46) Q | 38.00 (36.65;39.21) Q | 37.50 (36.00;38.39) Q | 31.28 (27.28;32.72) \$** |
| GA birth (w) | 39.72 (37.14;40.43) \$Q | 39.14 (37.93;39.93) \$Q | 37.65 (36.32;38.72) °Q* | 31.72 (27.86;33.14) \$** |
| Birth weight (g) | 3465 (2923.75;3695.0) \$Q | 3080.0 (2710.0;3552.5) Q | 2850 (2465;3260) Q* | 1425.0 (992.0;1730.0) \$** |
| Birth weight % | 50.00 (21.25;75.00) Q | 25.00 (10.00;62.50) | 25.00 (10.00-68.75) | 25.00 (10.00;25.00) * |
| Hemoglobin (g%) | 12.35 (11.53;12.80) | 12.10 (11.75;12.90) | 11.95 (10.90;12.88) | 12.10 (11.40;13.10) |
| Thromb (x1000/mm³) | 207.50 (168.25;235.50) | 208.00 (166.50;241.00) | 182 (152;229) | 176.00 (150.0;209) |
| ASAT (U/L) | 17.00 (15.00;19.25) | 18.00 (15.00;22.50) | 18.00 (15.00;24.00) | 19.00 (16.00;25.50) |
| ALAT (U/L) | 11.00 (9.00;12.25) Q | 12.00 (9.00;14.50) | 12.00 (9.00;17.25) | 16.00 (10.00;23.00) * |
| Uric Acid (μmol/L) | 4.65 (3.88;5.70) \$°Q | 5.48 (4.67;6.49) \$Q* | 5.95 (5.03;6.98) ** | 6.60 (5.40;7.70) °* |
| ProtU24h (mg) | 144.50 (112.75;174.50) \$Q | 164.0 (111.5;204.0) \$Q | 786 (434;1639) Q°* | 2543 (838.0;7322.0) \$** |
| Creat Clear (ml/min) | 131.07 (106.14;154.04) | 125.73 (104.16;157.73) | 121.94 (94.96;151.62) | 116.72 (93.27;141.85) |

* Significantly different from Uncomplicated Pregnancy (UP)

° Significantly different from Gestational Hypertension (GH)

S Significantly different from Late-onset Preeclampsia (LPE)

Q Significantly different from Early-onset Preeclampsia (EPE)

BMI : Body Mass Index at first antenatal visit

GA: gestational age (w)

Thromb: thrombocytes (x 1000/mm³)

ASAT: Aspartate Aminotransferase (U/L)

ALAT: Alanine Aminotransferase (U/L)

ProtU24h: 24 hour proteinuria (mg)

CreatClear: creatinine clearance (mL/min)

Table 2: Blood pressure values and impedance cardiography measurements

| | UP n=22 | GH n=41 | LPE n=56 | EPE n=31 |
|----------------------------|--------------------------------|----------------------------|----------------------------|-----------------------------|
| SBP (mm Hg) | 137.50 (122.00;147.00) \$°Q | 149.0 (141.50;159.50) * | 149.0 (135.25;163.75) * | 153.00 (141.00;166.00) * |
| DBP (mm Hg) | 87.50 (82.50;99.75) \$°Q | 98.0 (94.50;104.0) * | 98.00 (93.0;103.0) * | 102.0 (96.0;108.0) * |
| MAP (mm Hg) | 99.50 (93.75;111.50) \$°Q | 112.0(107.0;118.0) * | 110.0 (103.0;117.75) * | 113.0(108.0;122.0) * |
| Heart rate (bpm) | 97.0 (84.50;106.50) | 94.0 (89.0;105.5) \$ | 90.0 (82.0;102.5) ° | 94.0 (86.0;105.0) |
| Stroke volume (ml) | 77.50 (67.00;93.25) | 82.0(64.0;94.5) | 85.00 (61.00;99.00) | 75.00 (67.00;90.0) |
| Card output (L/min) | 7.30 (6.55;8.10) | 7.50 (6.25;8.80) | 7.70 (6.10;9.08) | 7.10 (6.20;8.10) |
| VI (1/1000/s) | 59.50 (50.75;65.25) \$°Q | 46.00 (39.50;58.00) * | 45.00 (38.25;55.75) * | 45.00 (35.00;56.00) * |
| ACI (1/100/s²) | 111.50 (86.5;147.0) \$°Q | 76.00 (59.00;102.50) * | 84.00 (6.50;98.25) * | 80.00 (58.00;108.75) * |
| TFC (1/kOhm) | 27.05 (24.85;29.60) \$Q | 24.75 (24.75;29.45) \$Q | 30.60 (27.85;34.85) Q** | 34.10 (29.20;39.00) \$** |

* Significantly different from Uncomplicated Pregnancy (UP)

° Significantly different from Gestational Hypertension (GH)

\$ Significantly different from Late-onset Preeclampsia (LPE)

Q Significantly different from Early-onset Preeclampsia (EPE)

SBP: Systolic blood pressure (mm Hg)

DBP: Diastolic blood pressure (mm Hg)

MAP : Mean arterial pressure (mm Hg)

Card Output: Cardiac output (L/min)

VI : Aorta flow velocity index (1/1000/s)

ACI : Aorta flow acceleration index (1/100/s²)

TFC: thoracic Fluid Content (1/kOhm)

Table 3: Doppler-ECG measurements

| | UP n=22 | GH n=41 | LPE n=56 | EPE n=31 |
|-------------------------|----------------------------|----------------------------|----------------------------|-----------------------------|
| LK RIVI | 0.330 (0.295;0.420) \$Q | 0.360 (0.32 ;0.428) Q | 0.40 (0.34;0.45) * | 0.427 (0.37 ;0.510) °* |
| RK RIVI | 0.308 (0.27;0.35) \$Q | 0.33 (0.282;0.389) \$Q | 0.38 (0.33;0.44) Q°* | 0.439 (0.367;0.544) \$°* |
| HVI | 0.220 (0.146;0.430) \$Q | 0.270 (0.165;0.784) Q | 0.52 (0.20;1.10) Q* | 0.920 (0.427;1.573) \$°* |
| LK VPTT (sec) | 0.437 (0.325;0.528) Q | 0.410 (0.345;0.467) Q | 0.37 (0.33;0.44) Q | 0.327 (0.270;0.393) \$°* |
| RK VPTT (sec) | 0.40 (0.340;0.475) Q | 0.40 (0.355;0.477) \$Q | 0.38 (0.32;0.42) ° | 0.335 (0.289;0.404) °* |
| L VPTT (sec) | 0.320 (0.265;0.395) Q | 0.300 (0.227;0.377) | 0.300 (0.205;0.410) | 0.247 (0.170;0.343) * |
| L Aut RI | 0.520 (0.415;0.607) Q | 0.550 (0.440;0.707) Q | 0.549 (0.468;0.680) Q | 0.707 (0.587;0.772) \$°* |
| L Aut PI | 0.710 (0.530;0.865) Q | 0.750 (0.570;1.097) Q | 0.755 (0.618;1.028) Q | 1.095 (0.833;1.261) \$°* |
| R Aut RI | 0.457 (0.409;0.647) Q | 0.460 (0.390;0.647) Q | 0.515 (0.430;0.618) Q | 0.717 (0.560;0.770) \$°* |
| R Aut PI | 0.570 (0.515;0.947) Q | 0.610 (0.490;0.953) Q | 0.702 (0.553;0.890) Q | 1.112 (0.780;1.248) \$°* |
| L Aut APTT (sec) | 0.320 (0.267;0.375) \$Q | 0.287 (0.252;0.340) \$Q | 0.274 (0.231;0.310) Q°* | 0.227 (0.218;0.288) \$°* |
| R Aut APTT (sec) | 0.340 (0.285;0.405) \$Q | 0.303 (0.253;0.340) \$Q | 0.272 (0.233;0.308) Q°* | 0.235 (0.209;0.290) \$°* |

* Significantly different from Uncomplicated Pregnancy (UP)

° Significantly different from Gestational Hypertension (GH)

\$ Significantly different from Late-onset Preeclampsia (LPE)

Q Significantly different from Early-onset Preeclampsia (EPE)

LK RIVI : Left kidney, renal interlobar vein impedance index

RK RIVI: Right kidney, renal interlobar vein impedance index

HVI: Hepatic vein impedance index

LK VPTT: Left kidney, venous pule transit time (sec)

RK VPTT : Right kidney, venous pule transit time (sec)

L VPTT: Liver venous pule transit time (sec)

L Aut RI: Left Uterine Arcuate Artery Resistivity index

L Aut PI : Left Uterine Arcuate Artery Pulsatility index

R Aut RI: Right Uterine Arcuate Artery Resistivity index

R Aut PI: Right Uterine Arcuate Artery Pulsatility index

L Aut APTT: Left Uterine Arcuate Artery Pulse transit time (sec)

R Aut APTT: Right Uterine Arcuate Artery Pulse transit time (sec)

Table 4: Summary of most important findings of Tables 2 & 3. Arrows indicate significant differences relative to uncomplicated pregnancy.

| Blood pressures | | | | | |
|------------------------------|----------|--|----|-----|-----|
| | | | GH | LPE | EPE |
| | SBP | | ↑ | ↑ | ↑ |
| | DBP | | ↑ | ↑ | ↑ |
| | MAP | | ↑ | ↑ | ↑ |
| Arterial hemodynamics | | | | | |
| | | | GH | LPE | EPE |
| Aorta | VI | | ↓ | ↓ | ↓ |
| | ACI | | ↓ | ↓ | ↓ |
| Ut Arc Art | Rt APTT | | | ↓ | ↓ |
| | Lt APTT | | | ↓ | ↓ |
| | R RI | | | | ↑ |
| | L RI | | | | ↑ |
| Venous hemodynamics | | | | | |
| | | | GH | LPE | EPE |
| Rt kidney | Rt RIVI | | | ↑ | ↑ |
| | Rt VPTT | | | | ↓ |
| Lt kidney | Lt RIVI | | | ↑ | ↑ |
| | Lt VPTT | | | | ↓ |
| Liver | Hep VI | | | ↑ | ↑ |
| | Hep VPTT | | | | ↓ |

GH : Gestational hypertension
 LPE : Late onset preeclampsia
 EPE : Early onset preeclampsia
 ACI : Aorta flow acceleration index
 Rt : Right
 APTT : Arterial pulse transit time
 RIVI : Renal Interlobar vein impedance index
 Hep VI : Hepatic vein impedance index

SBP : Systolic blood pressure
 DBP : Diastolic blood pressure
 MAP : Mean arterial pressure
 VI : Aorta flow velocity index
 Ut Arc Art : Uterine Arcuate Artery
 Lt : Left
 RI : Right resistivity index
 VPTT : Venous pulse transit time
 Hep VPTT : Hepatic vein pulse transit time

Figure captions

Figure 1

Flow chart of inclusions and exclusions in this study from the total number of women, admitted for hypertension in pregnancy to the Fetal Maternal Medicine Unit of Ziekenhuis Oost Limburg Genk Belgium during the study period. EH: essential hypertension, PE : preeclampsia, IUGR: Intra-uterine growth restriction, HELLP : Hemolysis Elevated Liver enzymes Low Platelets, Atypical PE: non-hypertensive proteinuria and/or elevated liver enzymes and/or low platelets.

Figure 2

Schematic presentation of the intra-abdominal locations where combined ECG-Doppler assessment were performed in study subjects: Hepatic Veins, Renal Interlobar Veins and Uterine Arcuate Arteries. Next to this, blood flow velocity characteristics in the thoracic aorta were assessed using Impedance Cardiography. (Figure adapted from <http://www.cancer.gov/images/cdr/live/CDR649519-750.jpg>).

Figure 1

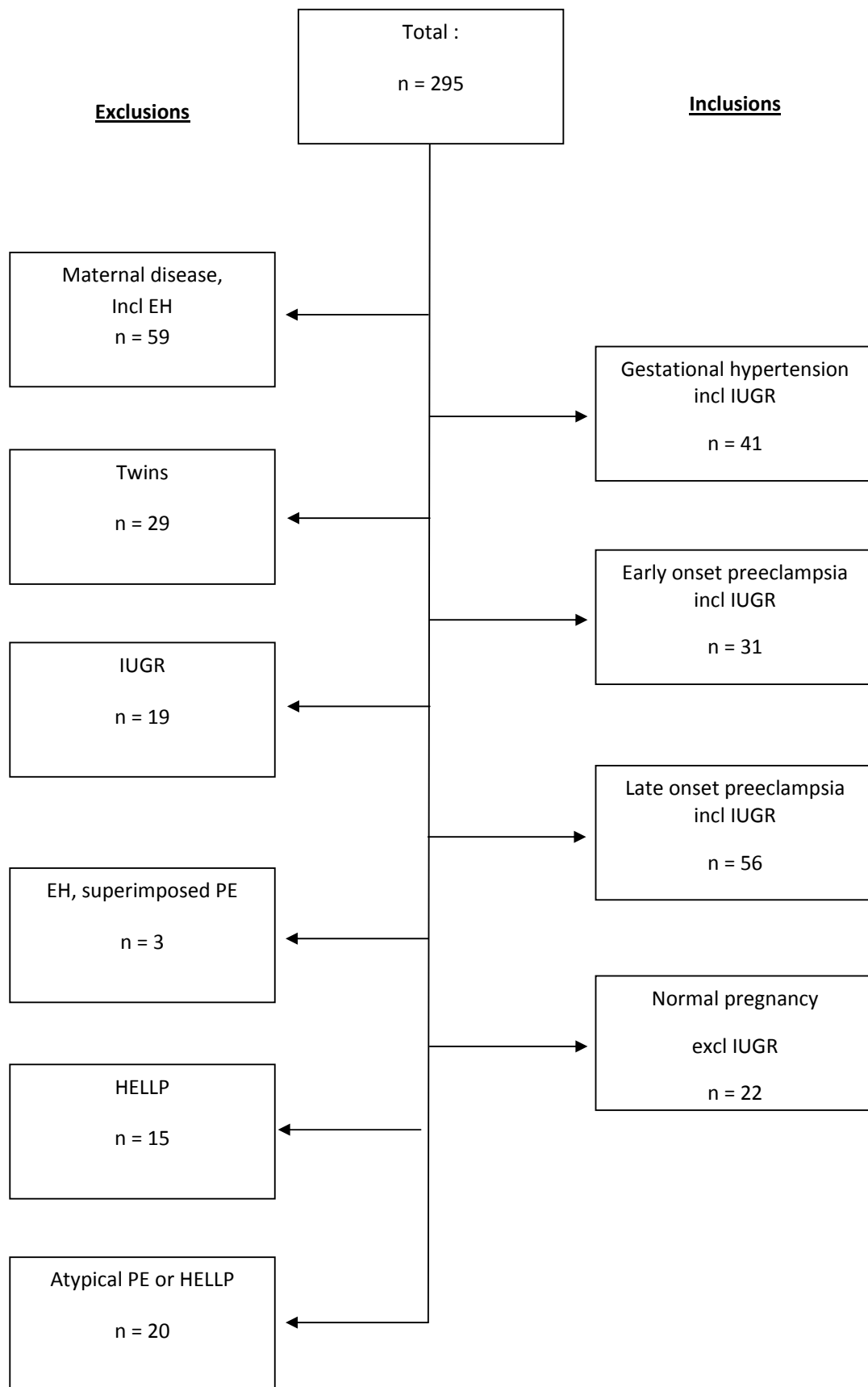
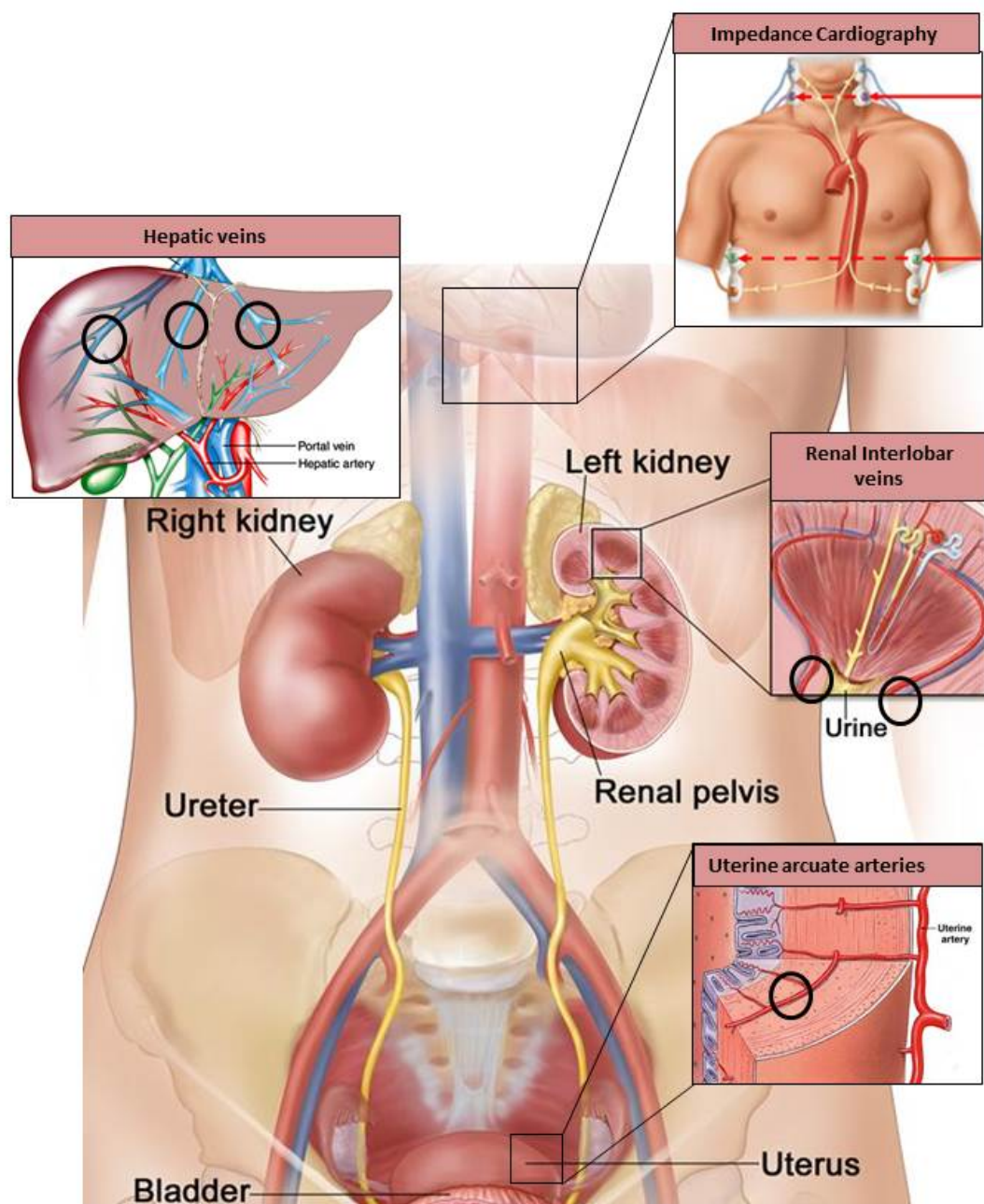


Figure 2



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