Value of non-invasive hemodynamic assessment in hypertensive disorders of pregnancy (HDP)

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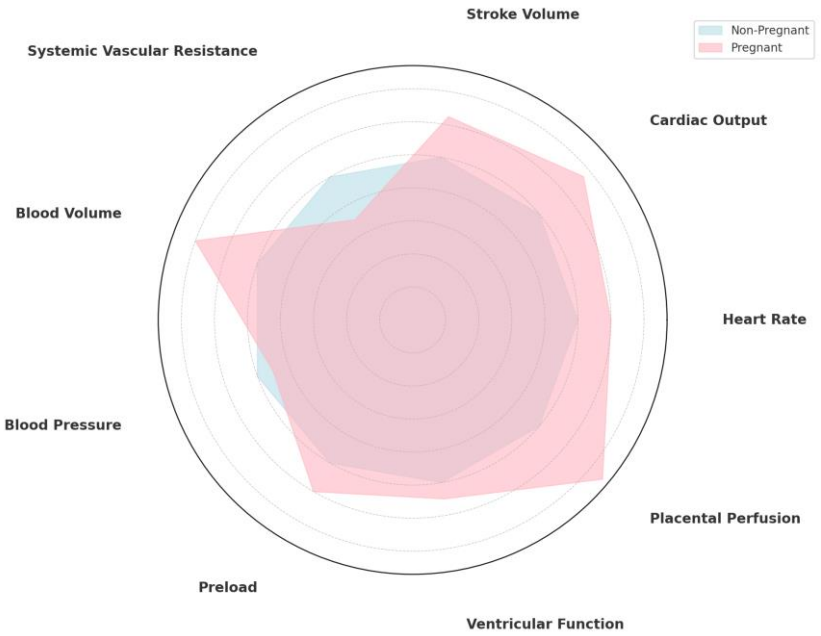
- ***Physiological cardiovascular adaptations during pregnancy***
- ***Impaired Maternal Cardiovascular Adaptation***
- ***Risks of HDP During and After Pregnancy***
- ***Principles of Hemodynamic Assessment***
- ***Hemodynamic Changes Associated with HDP***
- ***Clinical Relevance of Hemodynamic Assessment in HDP***

Hemodynamic changes during pregnancy

Characteristics	Non-Pregnant Woman	Physiological Pregnancy
Heart Rate	Normal (60-80 bpm)	↑ 10-30 bpm (70-90 bpm)
Stroke Volume	60-80 ml/beat	↑ 20-30% (70-90 ml/beat)
Cardiac Output	4-5 L/min	↑ 30-40% (6-7.5 L/min)
Systemic Vascular Resistance	Normal (1226-1435 dynes/sec/cm^5)	↓ up to 30% (880-1270 dynes/sec/cm^5)
Blood Volume	Approximately 5 L	↑ 30-50% (6.5-7.5 L)
Blood Pressure	Normal (120/80 mmHg)	↓ Slightly in early pregnancy Normal in 3rd trimester
Preload	Normal	↑
Ventricular Function	Normal ventricular size	Mild left ventricular hypertrophy
Placental Perfusion	Not applicable	↑ to support the fetus



Hunter S, Robson SC. Adaptation of the maternal heart in pregnancy. Br Heart J. 1992 Dec;68(6):540-3

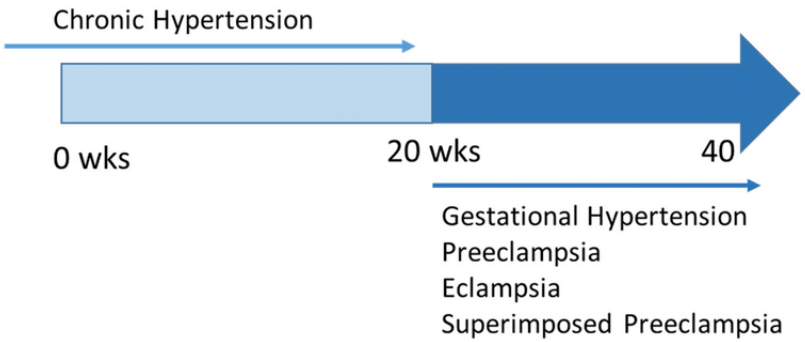
Mechanisms of physiological cardiovascular adaptation

Endocrine/Hormonal Mechanisms **Oestrogen, Progesterone** **Relaxin, NO**	Renal vasodilation Vascular compliance
Renin-Angiotensin-Aldosterone System (RAAS)	Volume regulation Sodium retention
Sympathetic Nervous System Activity	Maintain blood pressure

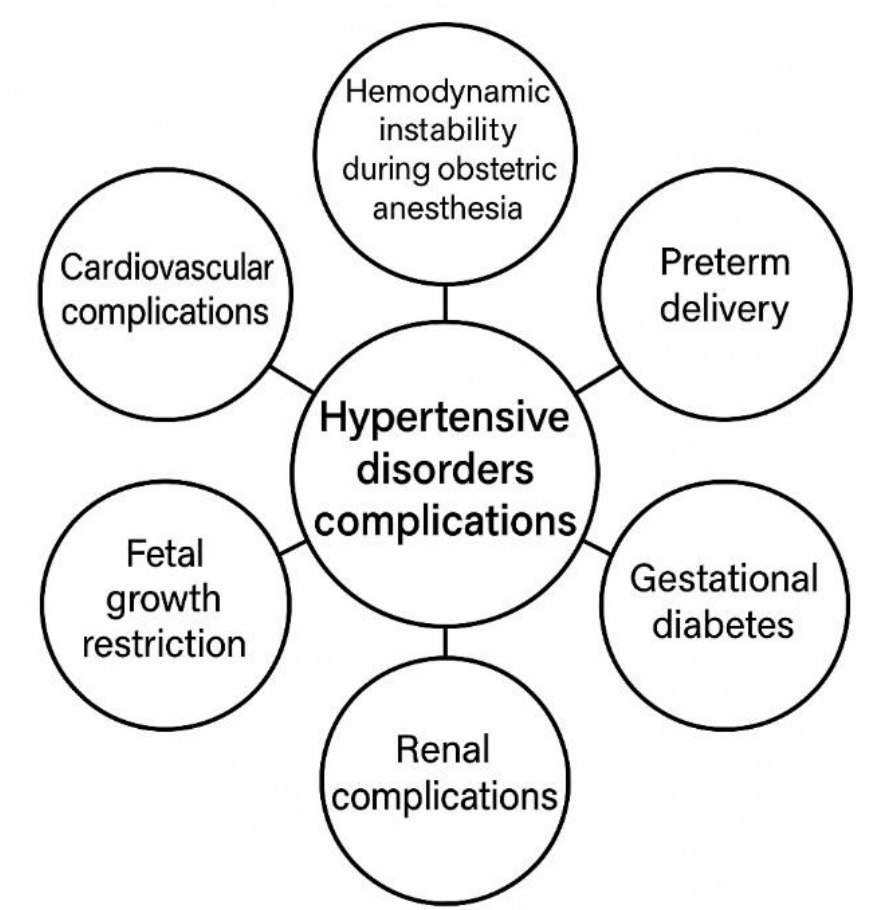
Disruptions in these homonal physiological adjustments
Impairs maternal cardiovascular adaptation

Changes the maternal hemodynamic profile
HDP

What are these patients at risk During pregnancy?



Target organ involvement



Cardiol Clin. Author manuscript; available in PMC 2022 February 01.

What are these patients at risk After pregnancy?

Long term impact of preeclampsia

Cardiovascular	Neurovascular	Metabolic	Renal	Central nervous system
Chronic hypertension	Stroke	Type 2 diabetes	Glomerular dysfunction	Cognitive dysfunction
Ischemic heart disease	Retinal detachment	Metabolic syndrome	Proteinuria	Retinopathy
Atherosclerosis	Diabetic retinopathy	Obesity		White-matter lesions
Cardiomyopathy		Dyslipidemia		
Thromboembolism				

Is the heart is having permanent damage ?

→ Screening

→ Targeted clinical follow-up

→ hemodynamic evaluation during pregnancy

AM J Obstet Gynecol MFM doi: 10.1016/j.ajogmf.2024.101371. Epub 2024 Apr 6

Hypertensive disorders of pregnancy

How to monitor?

- BP measurements
- Does not reflect CV changes

A **suboptimal adaptation of the maternal cardiovascular system** has been identified in the **pathophysiology of preeclampsia** highlighting the need for **more comprehensive hemodynamic assessments** beyond blood pressure monitoring

- ***Modern approach to pregnancy monitoring***
- From single parameter
- To whole hemodynamic profile

Hypertensive disorders of pregnancy

Is maternal hemodynamics difficult to investigate?

- The physiological adaptations of the pregnancy affects the measurements of hemodynamic parameters

- Which monitoring device?

The hemodynamic monitoring tool should be:

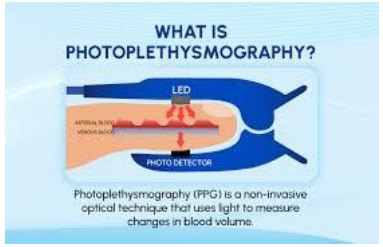
1. **Simple**
2. **Non-invasive**
3. **Non-compromising**
4. **Reproductible**
5. **Easy to learn**
6. **Easily accessible**

- ***Which cardiovascular changes are we searching for?***

Hypertensive disorders of pregnancy

How to investigate hemodynamic profile

Techniques	Principes	Avantages
Échocardiographie	Utilise les ultrasons pour visualiser le cœur, mesurer la vitesse du flux sanguin et les dimensions des cavités	Haute précision, visualise les structures et la fonction cardiaque
Ultrasonographie Doppler (par exemple, USCOM 1A)	Utilise les décalages Doppler pour mesurer les vitesses de flux sanguin dans les gros vaisseaux	Portable, largement disponible
Cardiographie par bioimpédance (ICG, par exemple, ICON) et Bioimpédance thoracique (TEB, par exemple, PhysioFlow)	Mesure les changements d'impédance thoracique causés par le volume de sang circulant dans l'aorte (ICG) ou par les changements de résistance thoracique (TEB)	Non invasif, monitoring continu, portable
Bioreactance (NICOM, par exemple, Cheetah Medical)	Semblable à la bioimpédance, mais mesure le déphasage des courants électriques traversant le thorax	Offre une meilleure précision par rapport à la bioimpédance traditionnelle, monitoring continu, portable
Photopléthysmographie (PPG, par exemple, Masimo Radical-7)	Mesure les variations de l'absorption de la lumière par le sang	Non invasif, portable, monitoring continu
Analyse de l'onde de pouls (par exemple, ClearSight/ Nexfin)	Utilise un brassard autour du doigt pour mesurer en continu les variations de volume sanguin avec la contre-pression, puis analyse l'onde de pouls. Initialement calibré via l'oscillométrie pour obtenir la pression artérielle	Non invasif, monitoring continu, utilisé pendant le travail et l'accouchement
IRM cardiaque (par exemple, Siemens MAGNETOM)	Imagerie par résonance magnétique pour mesurer le flux sanguin à travers l'aorte et les autres gros vaisseaux	Haute précision, évaluation détaillée de la fonction cardiaque
Principe de Fick (Version non invasive, par exemple, Innocor)	Estime le débit cardiaque en fonction de la consommation d'oxygène et de la différence artérioveineuse en oxygène	Non invasif, version adaptée pour obstétrique



Rev Med Suisse 2025 ; 21 : 34-40 | DOI 10.53738/REVMED.2025.21.900-1.34

Hemodynamic monitoring in HDP

Transthoracic echocardiography (TTE)

- **The primary tool for hemodynamic evaluation**
- Requires a **trained specialist**

- **Cardiac output** **CO** (ml) = SV × HR

- **Cardiac geometry**

Shape, structure, and dimensions of the heart structures

- **Systemic vascular resistance** **SVR** in dynes/sec/cm^5: **MAP × 80 / CO**

→ Assess heart adaptation to various situation

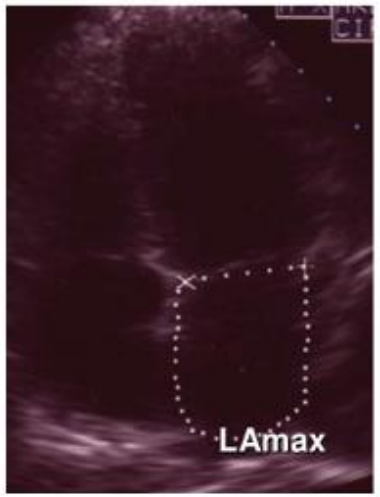
→ Detect structural abnormalities

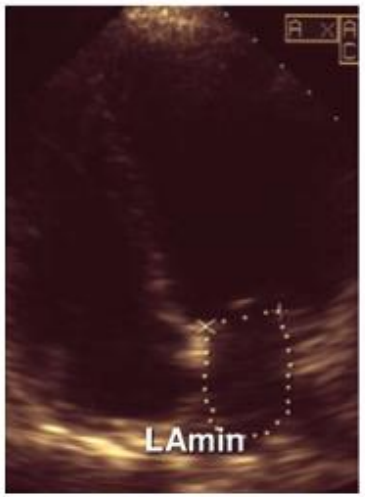
→ Monitor the evolution after a treatment

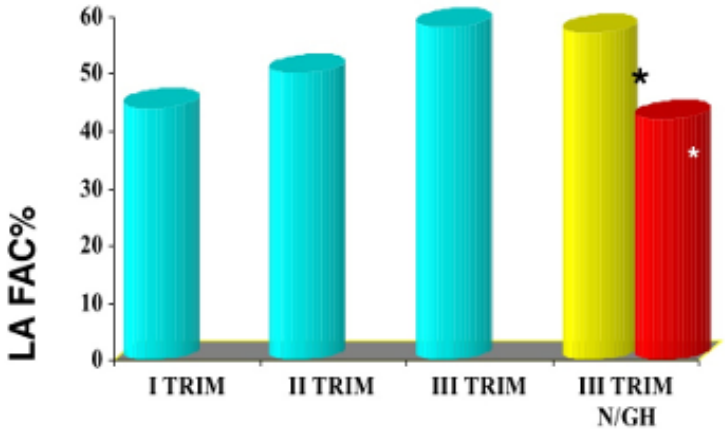
Hemodynamic monitoring in HDP

Transthoracic echocardiography (TTE)

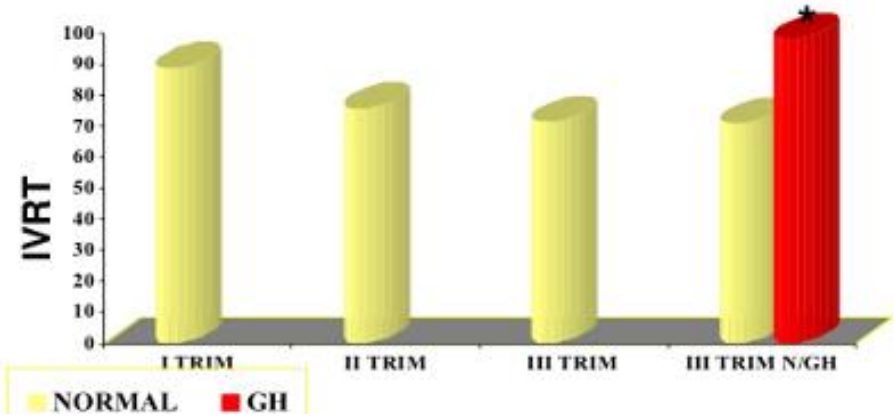
1. Maternal Diastolic Dysfunction







- ↓ LA FAC : **(LA max –LA min) / LA max**
- Difficult voiding from LA to LV
- High LV end systolic pressure
- Longer time for LVp ⟨ LA p
- Transmitral flow is altered
- ↑ IVRT

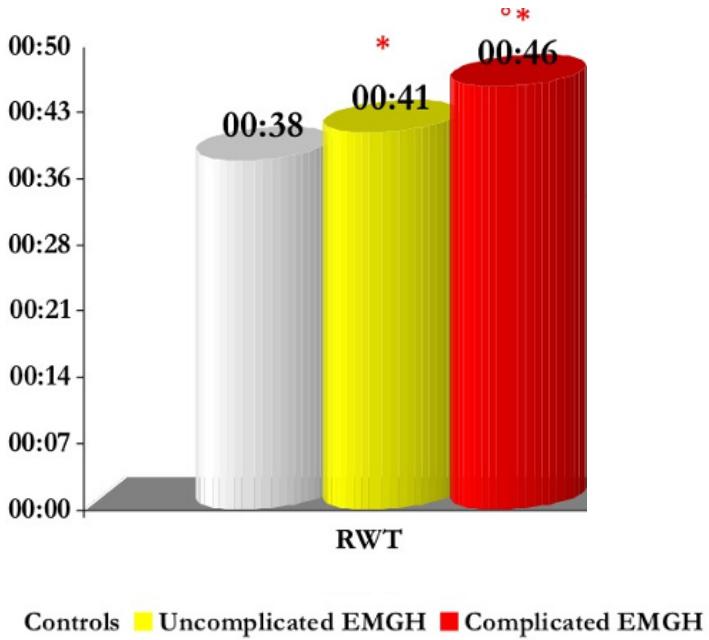


Volume 37, Issue 5, May 2001; Pages 1209-1215 https://doi.org/10.1161/01.HYP.37.5.1209

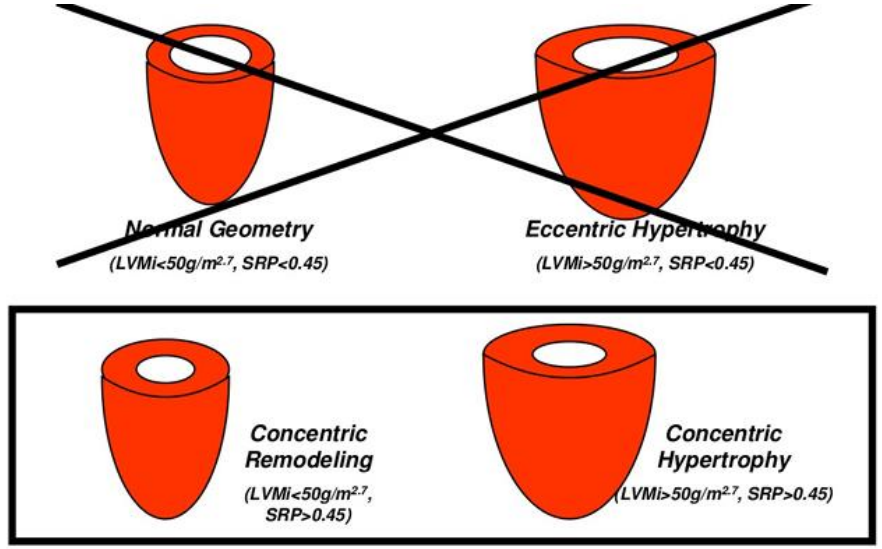
Hypertensive disorders of pregnancy

Transthoracic echocardiography (TTE)

2. Left Ventricular Geometry: RWT



$$\text{RWT} = \frac{2 \times \text{Posterior Wall Thickness (PWT)}}{\text{Left Ventricular Internal Diameter in Diastole (LVIDd)}}$$



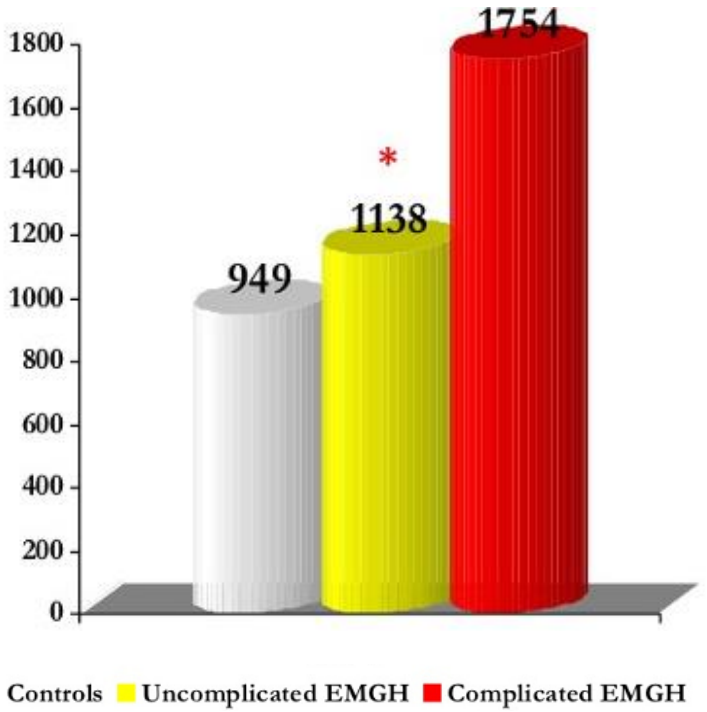
Proposed Classification of Gestational Hypertension	Low-Risk Hypertensive Group	High-Risk Hypertensive Group
Concentric Geometry (RWT)	Absent (< 0.45)	Present (≥ 0.45)

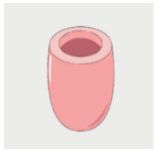
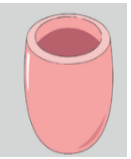
Ultrasound Obstet Gynecol 2002; 20: 452–457, Vasapollo et al Ultrasound Obstet Gynecol 2004; 24: 23–29

Hemodynamic monitoring in HDP

Transthoracic echocardiography (TTE)

3. High Total Vascular Resistance



Parameter	Normal Geometry (n=68)	Concentric Remodeling (n=31)	Eccentric Hypertrophy (n=12)	Concentric Hypertrophy (n=37)	P-value
Cardiac output, L	6.17 ± 1.13	4.81 ± 1.14	7.17 ± 1.22	5.37 ± 1.35	<0.001
Total vascular resistance, dyn·s·cm^{-5}	1362 ± 308	1864 ± 491	1094 ± 213	1700 ± 473	<0.001
Image Representing Geometries					

DOI: 10.1111/j.1471-0528.2006.01013.xwww.blackwellpublishing.com/bjog

Hemodynamic monitoring in HDP

Why to screen?

Maternal and fetal complications

Table 1. Main maternal and fetal/neonatal complications subsequently developed in women with gestational hypertension

Complications occurred in the study group	*n*, 92/268
Maternal complications	39
Appearance of proteinuria >300 mg/24 hours (pre-eclampsia)	17
Evolution towards moderate to severe gestational hypertension with induced preterm delivery <34 weeks	13
Placental abruption	3
HELLP syndrome (two women), coagulation abnormalities (two women), elevated liver enzymes (one woman), thrombocytopenia (one woman)	6
Fetal/neonatal complications	26
FGR	19
Admittance to neonatal intensive care unit	5
Perinatal death	2
Maternal and fetal/neonatal complications	27
Pre-eclampsia and FGR	18
Evolution towards moderate to severe gestational hypertension and FGR with induced preterm delivery <34 weeks	8
HELLP syndrome and neonatal death	1
Total complications	92

Risk factors of complications

Table 6. Proposed classification of gestational hypertension

	Low-risk hypertensive group	High-risk hypertensive group
TVR	<1340 dyn seconds/cm^5	≥1340 dyn seconds/cm^5
Concentric geometry (RWT)	Absent (<0.45)	Present (≥0.45)

Volume 41, Issue 3, 1 March 2003; Pages 469-475 https://doi.org/10.1161/01.HYP.0000058001.67791.0A

Hypertensive disorders of pregnancy

Point of care ultrasound (POCUS)

- **Rapid, non-invasive, bedside,** simple views
- Obstetric ultrasound device
- Performed directly by a **trained healthcare provider**
- Ventricular filling and contraction kinetics → **cardiac function**
- The compressibility of the inferior vena cava → **blood volume status**
- Pulmonary ultrasound → **volume overload**, **B-lines**
- **IV access, difficult airways, difficult epidural**

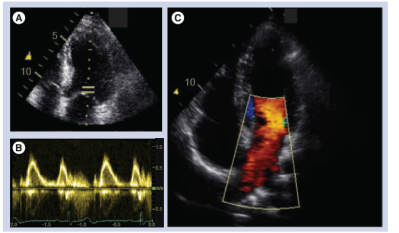
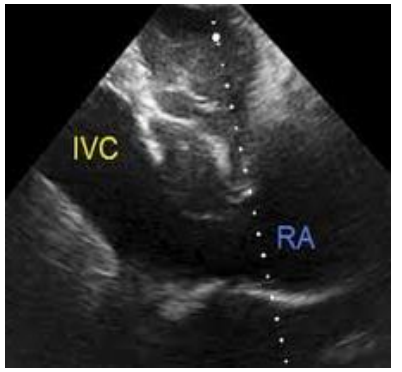
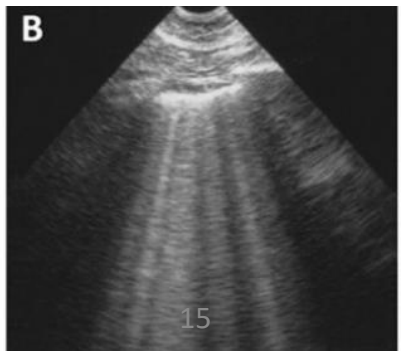


Figure 2. Left ventricular filling. Position of the pulsed wave Doppler sample **(A)**, resulting in a Doppler signal of the mitral inflow velocities, which shows the early and atrial left ventricular filling phases **(B)**. Color Doppler image of the left ventricular inflow tract **(C)**.





→ Managing **maternal complications** in emergency settings or in the delivery room

Hemodynamic monitoring in HDP

Non-invasive monitoring devices

- **Ultrasonic Cardiac Output Monitor (USCOM)**

Many current studies on maternal hemodynamics

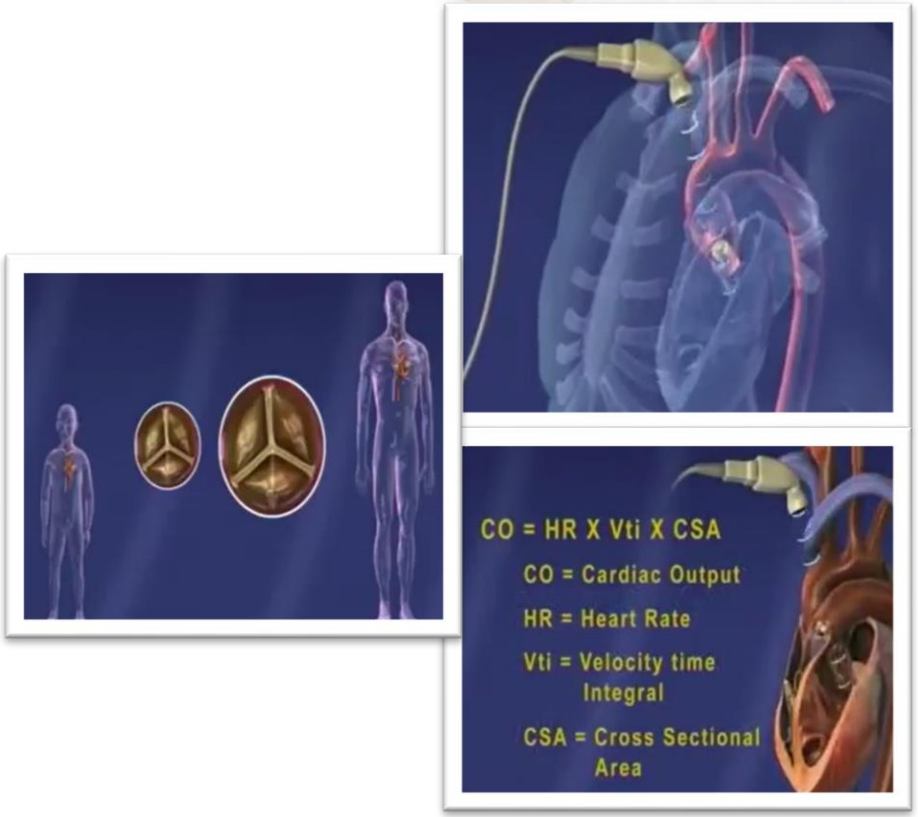
- **How It Works:** Combining **Doppler ultrasound** and **patient-specific data**

A hand-held transducer is placed on the suprasternal notch

Emits a continuous wave Doppler signal

Measures blood flow velocity across heart valves

Uses validated algorithms to estimate valve diameter



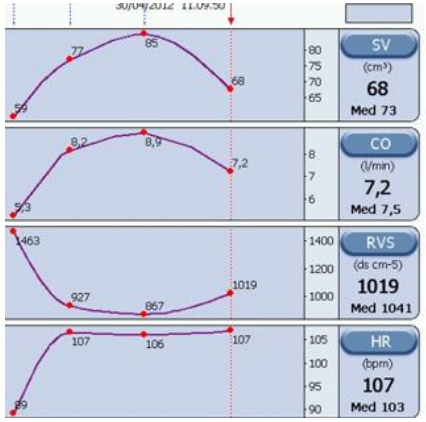
- Assess hemodynamic status in normotensive pregnancies and HDP
- Appears to overestimate CO , Error rates ≥ 30% (position difference)

Mulder E, Basit S, Oben J, et al. Accuracy and precision of USCOM versus transthoracic echocardiography before and during pregnancy. Pregnancy Hypertens. 2019 Jul;17:138-43.

Hypertensive disorders of pregnancy

USCOM

- In pregnancy, using a single technique with **method-specific reference values**
- Eliminates the risk of over- or underestimation
- Monitors **trends in measurements** (as important as tracking **absolute values)**
- Identifies effect of therapeutic interventions



Reference range of maternal hemodynamic parameters by trimester

*the average values of various hemodynamic parameters in a population of **531 low-risk pregnant women***

Measurement	1st Trimester	2nd Trimester	3rd Trimester
Heart Rate (bpm)	77.0 ± 10.86	81.09 ± 10.82	86.04 ± 13.13
Systemic Vascular Resistance (SVR) (dynes/sec/cm^5)	1151.40 ± 228.29	983.66 ± 192.34	922.16 ± 156.52
Cardiac Output (CO) (L/min)	6.40 ± 1.19	7.24 ± 1.34	7.80 ± 1.36
Stroke Volume Variation (SVV) (%)	19.48 ± 7.89	21.45 ± 9.88	21.25 ± 9.50

Vonck S, Staelens AS, Bollen I, **Broekx** L, Gyselaers W. Why non-invasive maternal hemodynamics assessment is clinically relevant in early pregnancy: a literature review. BMC Pregnancy

Hypertensive disorders of pregnancy

USCOM

Maternal hemodynamic profiles by underlying pathologies

Pathology	CO	SVR	Blood Volume	Ventricular Characteristics
Preeclampsia without IUGR	High	Moderate to high	Reduced	Concentric hypertrophy
Preeclampsia with IUGR	Low	Very high	Reduced	Concentric hypertrophy, smaller heart
IUGR without preeclampsia	Normal or slightly low	Moderately elevated	Lower	Moderate ventricular hypertrophy
Early-onset preeclampsia (<34 weeks GA)	Low	Very high	Reduced	Concentric hypertrophy
Late-onset preeclampsia (>34 weeks GA)	High	Moderate	Reduced	Moderate hypertrophy
Obesity (BMI > 35 kg/m^2)	High	Low	Increased	Left ventricular hypertrophy
Gestational diabetes	Normal	Normal	Increased	Mild left ventricular hypertrophy

Comparison to normotensive controls at 24 WGA → changes before the appearance of any clinical symptoms

Rev Med Suisse 2025 ; 21 : 34-40 | DOI 10.53738/REVMED.2025.21.900-1.34

Valensise H, Farsetti D, Pisani I, et al. Friendly help for clinical use of adaptation to pregnancy. Ultrasound Obs tet Gynecol. 2020 Aug;56(2):240-6. maternal hemodynamics. J Matern Fetal Neonatal Med. 2021 Sep;34(18):3075-9.

Hypertensive disorders of pregnancy

USCOM

Maternal hemodynamic profiles by trimester and impact on HDP

1st trimester:

SVR > 1130 dynes/sec/cm5 , DC < 6,1 l/min

HDP x 11, IUGR x 25

At the time of PE diagnosis:

SVR : PE+ IUGR, PE, early-onset PE > control

CO: PE and IUGR, or early-onset PE < control

CO no significant difference : early vs late PE

→ The hemodynamic profile is not dependent on gestational age at onset

→ The hemodynamic profile is strongly associated with the presence or absence of IUGR

Di Pasquo E, Ghi T, Dall'Asta A, et al. Am J Obstet Gynecol. 2019 Dec;221(6):633. e1-633.e9.

Hypertensive disorders of pregnancy

Comparison of the characteristics of hypodynamic and hyperdynamic circulations

Characteristic	Hypodynamic Circulation	Hyperdynamic Circulation
CO (Cardiac Output)	Low	High
SVR (Systemic Vascular Resistance)	High	Low
Blood Volume	Reduced	Increased
Cardiac Remodeling/Response	Concentric left ventricular hypertrophy, smaller heart	Ventricular dilation
Clinical Contexts	Severe preeclampsia, preeclampsia with IUGR	Normal pregnancy, preeclampsia without IUGR, hyperthyroidism, severe anemia, sepsis

- Defines the cardiovascular phenotype
- Provides a rational basis for therapy selection, whether targeting CO or SVR lowering

Masini G, Foo LF, Tay J, et al. Preeclampsia has two phenotypes which require different treatment strategies. Am J Obstet Gynecol. 2022 Feb;226(2):S1006-18.
Ling HZ, Guy G, Nicolaides KH, Kametas NA. Longitudinal maternal cardiac function in hypertensive 40 WWW.REVMED.CH 15 janvier 2025 disorders of pregnancy. Am J Obstet Gynecol MFM. 2023 Feb;5(2):100824.

Summary & Take home messages

Clinical Relevance of Hemodynamic Monitoring

- Should be **non-invasive, simple, reproducible, accurate, and easy to learn**
- Can help differentiate the clinical profile of preeclampsia
- Can help predict the progression from mild to severe forms
- Can guide treatment, and optimize follow-up
- **A single, standardized technique** minimizes error and help monitor trends
- Future studies are needed to assess the impact on maternal and fetal outcomes

Summary & Take home messages

- **Maladaptation** of the maternal cardiovascular system → **hypertensive disorders of pregnancy**

- Key features of cardiovascular maladaptation is already present in the asymptomatic phase**:**

1. Diastolic dysfunction: ↓ LA FAC%, ↑ IVRT, ↑ RWT

2. ↓ SV , CO

3. ↑ SVR

- **Concentric LV hypertrophy** and **elevated SVR: predict progression to severe PE**

- **Hyperdynamic circulation: ↑ CO ↓ SVR**
- **Hypodynamic circulation: ↓ CO ↑ SVR**


THANK YOU!