

Fetal Growth Restriction

Role of Doppler Ultrasound

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GUIDELINES

ISUOG Practice Guidelines: diagnosis and management of small-for-gestational-age fetus and fetal growth restriction

Check for updates

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GUIDELINE

ISUOG Practice Guidelines (updated): use of Doppler velocimetry in obstetrics

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GUIDELINES

ISUOG Practice Guidelines (updated): performance of the routine mid-trimester fetal ultrasound scan

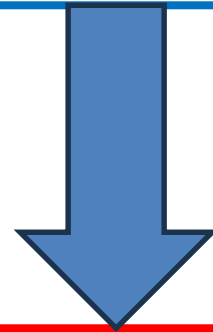
INTRODUCTION

- ❑ The evaluation of **fetal growth** is one of the key objectives of **prenatal care**.
- ❑ Fetal growth depends on several factors:
 - uteroplacental function,
 - maternal disease,
 - maternal cardiovascular function or cardiac disease,
 - maternal nutrition,
 - altitude,
 - smoking and illicit drug use,
 - other conditions: infection, aneuploidy and some genetic conditions
- ❑ *Uteroplacental insufficiency or dysfunction* represents one of the most frequent causes of abnormal growth in an otherwise normal fetus.
- ❑ Impaired fetal growth is associated with an increased risk of perinatal mortality and morbidity, and long-term **adverse infant outcome** and even non-communicable diseases in **adulthood**, such as hypertension, metabolic syndrome, insulin resistance, Type-2 diabetes mellitus, coronary heart disease and stroke.

INTRODUCTION

- ❑ Prenatal recognition of fetal growth restriction (**FGR**) is a major factor identified in strategies aimed at **preventing stillbirth**, in which **up to 30%** of cases are associated with FGR or small-for-gestational age (**SGA**) in the late third trimester.
- ❑ This lecture provides definitions of FGR (intrauterine growth restriction :IUGR) and its subtypes, and SGA, and the role of color Doppler ultrasound in the categorization and management of small fetuses.
- ❑ We assume that the pregnancy is singleton, pregnancy dating has been carried out correctly (preferably in the first trimester by ultrasound) and that there are no fetal pathologies, such as aneuploidy, congenital malformation or infection.

1. Use First trimester US for determining **gestational age(GA)**
2. Use fetal biometry for determining **fetal growth (FG)**
3. Compare FG with GA



- **FG within 10th to 90th percentile of GA :** **Appropriate for GA**
- **FG > 90th percentile of GA:** **Large for GA**
- **FG < 10th percentile of GA:** **Small for GA : Constitutional SGA or FGR**

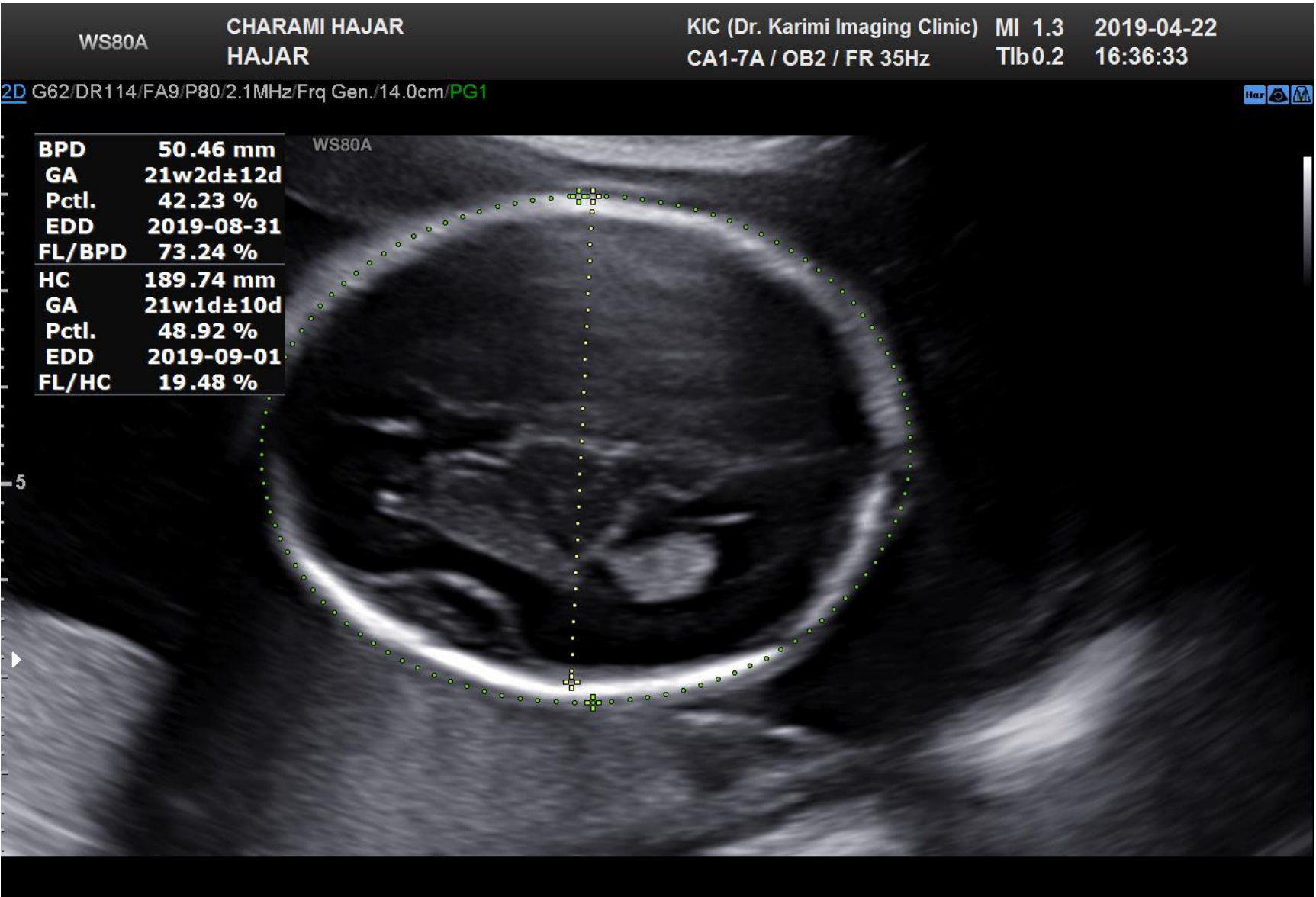
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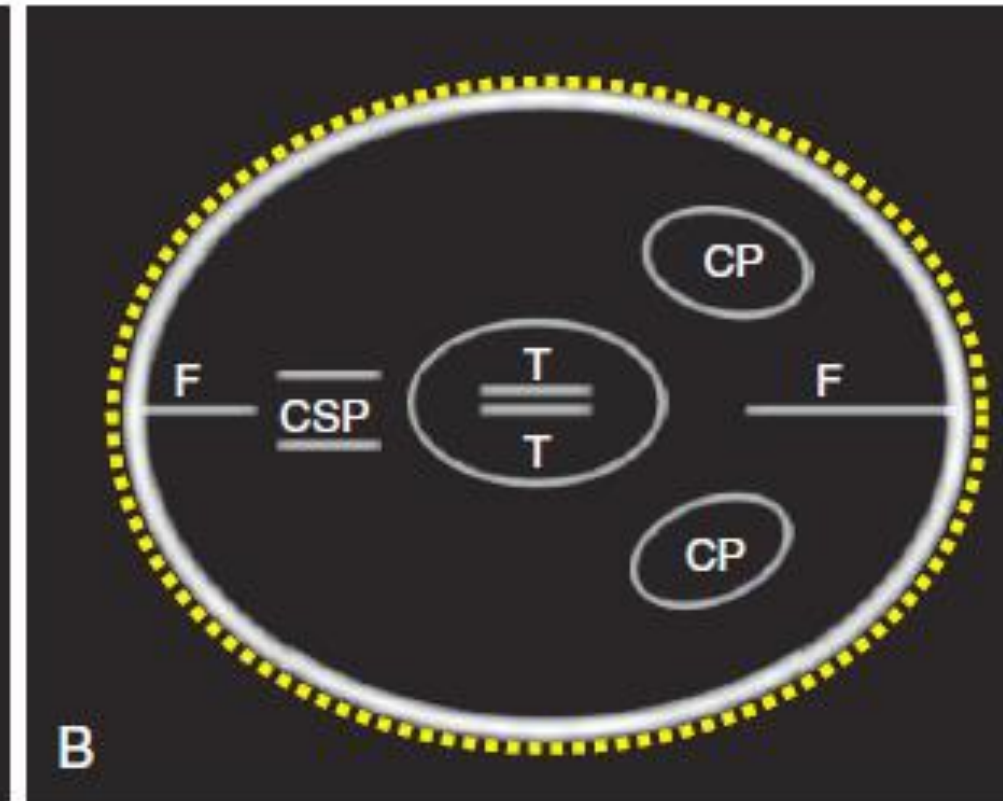
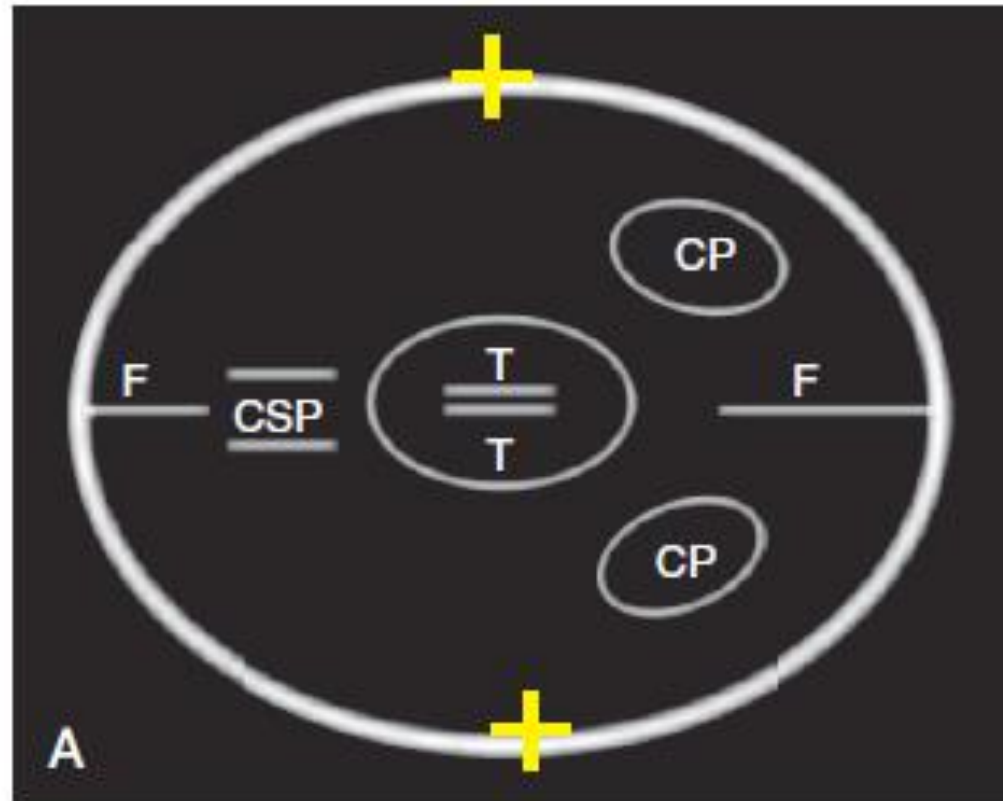
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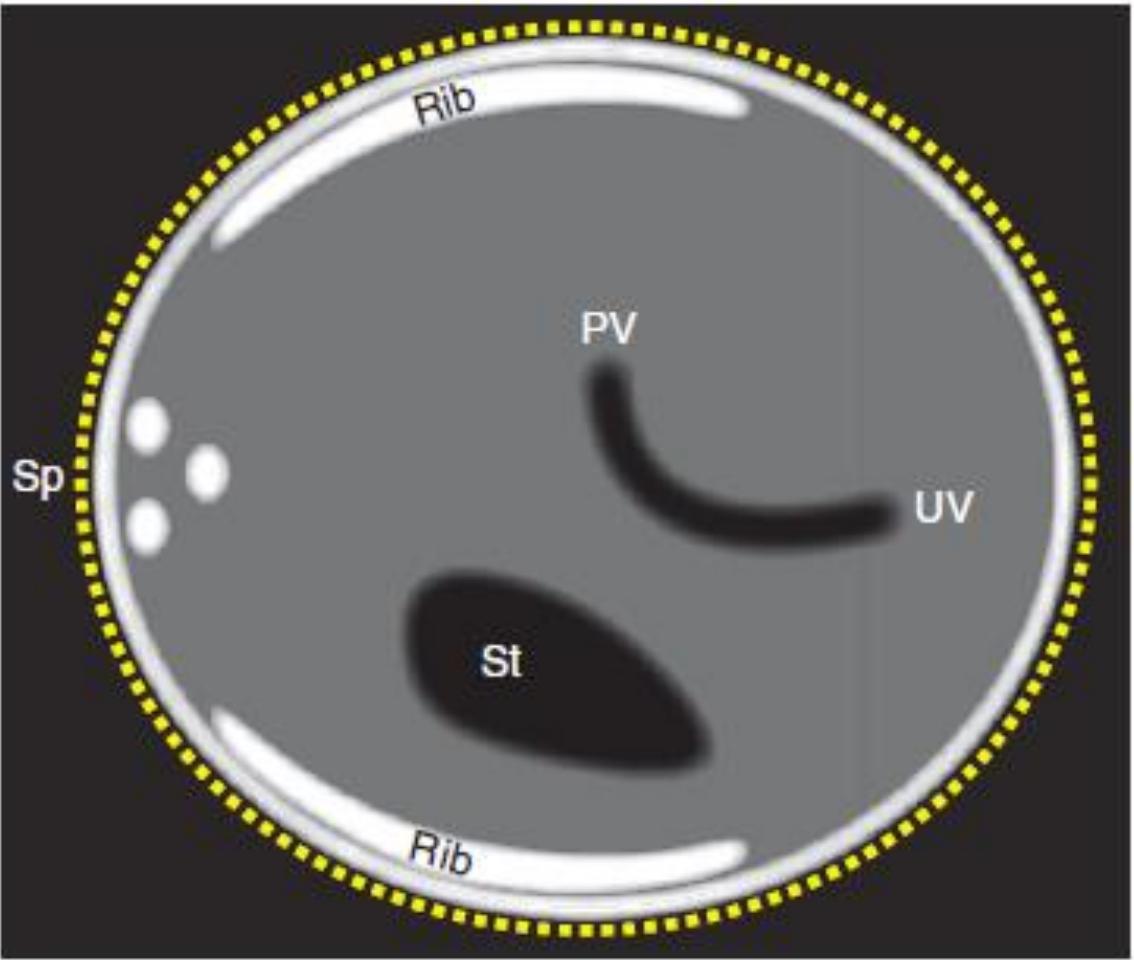
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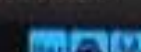
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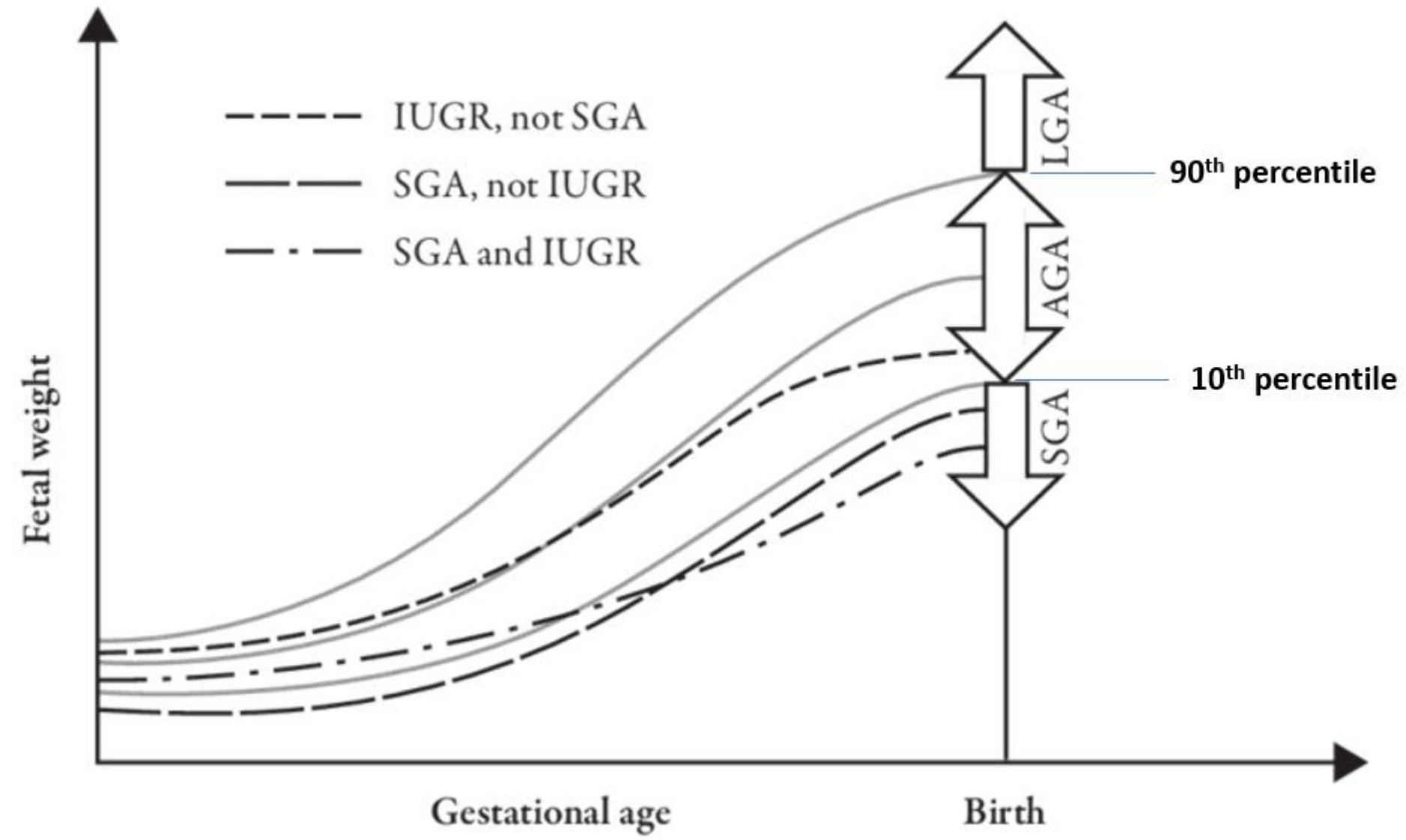


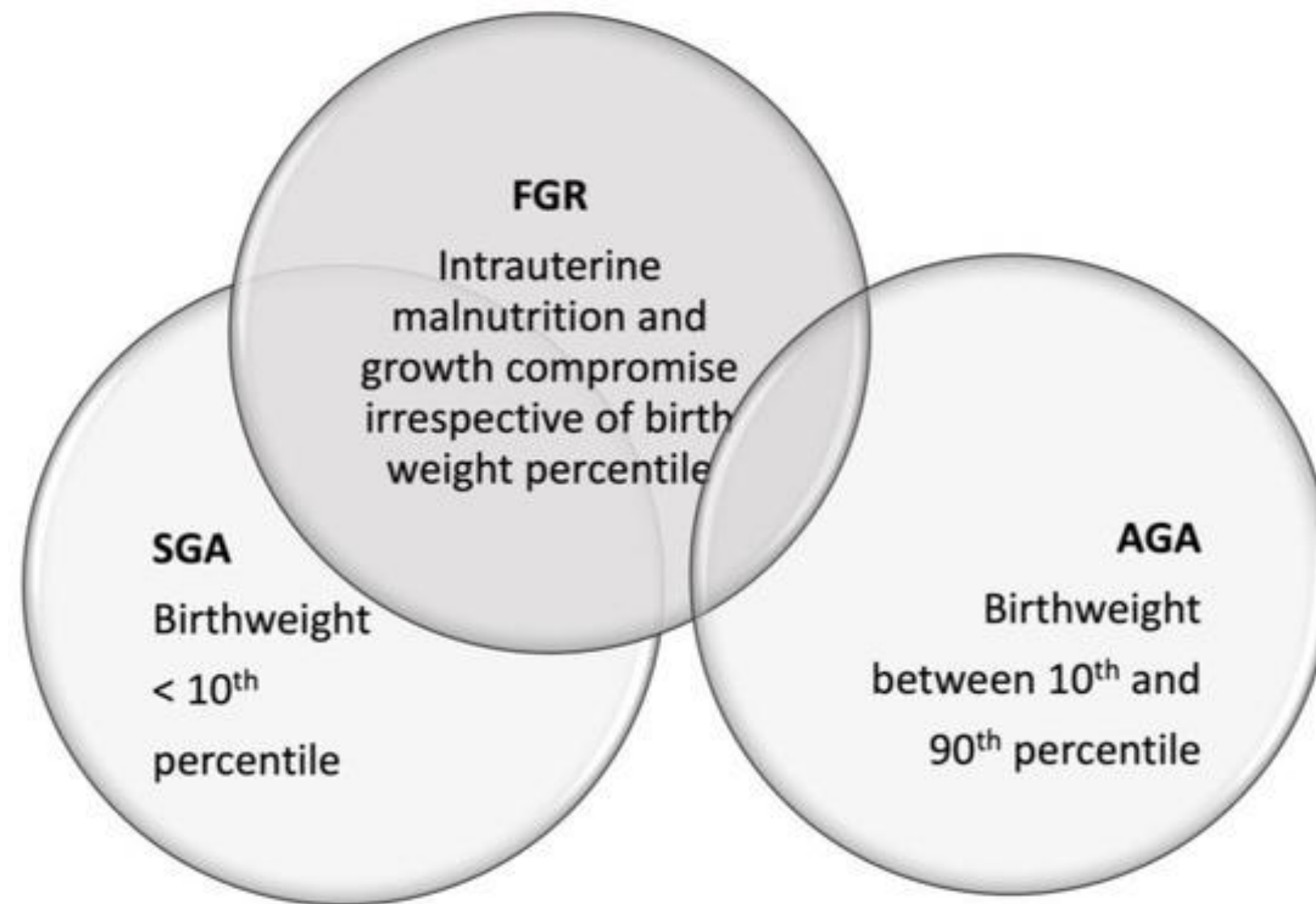
Definition of and distinction between small for gestational age and fetal growth restriction

- Fetal growth is a dynamic process and its assessment requires multiple observations of fetal size over time.
- The most common definition of SGA is EFW or AC below the 10th percentile of given reference ranges.
- Nevertheless, other thresholds have been described, such as the 5th and 3rd percentiles (the latter approximating to 2 SD) or a Z-score of -2 .

- ✓ FGR is a condition that is frequently, but unhelpfully, defined as the fetus failing to reach its genetically predetermined growth potential.
- ✓ The main distinction between SGA and FGR is that a SGA fetus may be small but not at increased risk of adverse perinatal outcome, while a fetus with size above the 10th percentile may be FGR and at increased risk of adverse perinatal and long-term outcome.
- ✓ Fetuses with birth weight below the 10th percentile are at increased risk of stillbirth and perinatal mortality, with those with birth weight below the 3rd percentile being at the highest risk.
- ✓ For this reason, fetal size at the lower extreme of the growth charts, for example **AC or EFW below the 3rd percentile for given growth charts, can be used as an isolated criterion to define FGR at any gestational epoch.**

AGA=appropriate for gestational age; LGA=large for gestational age.





small for gestational age (SGA), appropriate for gestational age (AGA) and fetal growth-restricted infants (FGR). Both SGA and AGA infants can be growth restricted.

Tools for diagnosis, surveillance and management of fetal growth restriction

In order to differentiate between SGA and FGR in cases in which the fetal size is below the 10th percentile, additional biophysical parameters are required:

- Evaluation of fetal growth velocity
- Customized growth charts
- Doppler velocimetric evaluation of placental and fetal circulations
- Biomarkers

Some of these biophysical parameters are also used to monitor fetal status and/or as delivery decision criteria (e.g. umbilical artery (UA) Doppler). Biophysical tools, such as ductus venosus velocimetry, biophysical profile (BPP) scoring and cardiotocographic (CTG) assessment of fetal heart rate short-term variation (STV), are not used as diagnostic criteria for FGR but for the surveillance and management of pregnancies already diagnosed as FGR.

Fetal growth velocity

There are several methods to evaluate fetal growth velocity, including use of longitudinal growth charts, assessment of deviation from growth-velocity charts and individualized growth assessment.

Overall, the objective is to evaluate the fetal growth trajectory and identify those fetuses that are deviating from their individual trajectory, indicating a failure to reach their growth potential. There is evidence to suggest that reduced fetal growth velocity in the third trimester is associated with increased risk of adverse outcome.

Reduced growth velocity is normally taken to be a fall between consecutive ultrasound scans of > 50 percentiles for AC or, more commonly, EFW.

Customized growth charts

In customized charts, the fetal weight and growth are adjusted for variables known to impact fetal size. These can include maternal height, weight, age, parity and ethnicity and fetal sex.

Adjustment for these variables is suggested to allow for better identification of SGA fetuses at risk of perinatal complications.

Biophysical profile scoring

The BPP score consists of the combined evaluation of fetal tone, gross body movement, breathing movement, amniotic fluid volume and heart-rate reactivity.

BPP score can predict both fetal pH and outcome. The relationship between altered BPP score and fetal pH seems to be consistent across gestational ages.

A score of ≤ 4 is associated with a fetal pH ≤ 7.20 , while a score of < 2 has a sensitivity of 100% for acidemia.

This correlation remains highly significant even when using a simplified BPP that is based on assessment of only fetal heart rate and amniotic fluid volume.

Cardiotocography and short-term variation

A reactive CTG (NST) virtually excludes fetal hypoxemia.

The fetal heart rate STV is a biophysical parameter obtained by computerized CTG (cCTG) that reflects autonomic nervous system function. In the context of FGR and the accompanying presence of severe hypoxemia or hypoxia, the fetal sympathetic and parasympathetic activity is altered, resulting in reduced fetal heart rate variation, and, thus, reduced STV.

cCTG and evaluation of STV have been validated against invasive testing in fetal hypoxemia and acidemia and represent the only objective measure of fetal heart rate. Visual inspection of conventional CTG does not provide the same information as cCTG, as CTG represents a largely subjective assessment with low intra- and interobserver reproducibility.

Biomarkers

Placental biomarkers have a potential role in screening, diagnosis and therapy of placental disease linked to hypertensive disorders of pregnancy and/or FGR.

Several placental factors have been investigated, including placental proteins as well as microRNA and mRNA. Some placental proteins, such as pregnancy-associated plasma protein-A, are biomarkers of placental function in the first trimester, though its predictive ability is limited.

The soluble **fms-like tyrosine kinase-1 (sFlt-1) to placental growth factor (PlGF) ratio** has been proposed as a short-term predictor to rule out pre-eclampsia in women in whom this condition is suspected clinically. Although some reports suggest that use of the sFlt-1/PlGF ratio might be helpful in the management of and differentiation between SGA and FGR, the lack of interventional trial data precludes the recommendation of these tests as an adjunct to ultrasound imaging.

Doppler velocimetry

- The rationale behind the application of Doppler velocimetry in fetal growth assessment is that it can **identify uteroplacental function** through evaluation of the uterine and umbilical arteries.
- Uteroplacental insufficiency is mediated through **spiral artery maladaptation** and alterations in the **villous vascular tree**.
- On the fetal side, Doppler velocimetry allows evaluation of the middle cerebral artery (MCA) and ductus venosus as fetal cardiovascular adaptation progresses from hypoxia to acidemia.
- A lack of physiological transformation of the uterine arteries from high- to low-resistance vessels is thought to reflect inadequate trophoblastic invasion of the spiral arteries, leaving a high-resistance circulation.
- The persistence of high uterine artery mean pulsatility index (PI) (above the 95th percentile) is associated with placental insufficiency and maternal vascular malperfusion of the placenta.

Doppler velocimetry

Doppler velocimetry plays a central role in **identification**, **surveillance** and **management** of FGR, because it allows for identification of uteroplacental insufficiency and/or fetal cardiovascular adaptation to hypoxemia.

Importantly, the two phenotypes of FGR, **early-onset** and **late-onset**, are characterized by different Doppler velocimetry patterns.

Doppler velocimetry

- ❑ Progressively **increasing PI in the UA** corresponds to a progressive reduction in the placental surface area available for gas and nutrient exchange and increased fetal afterload resistance, and is associated with **placental vascular insufficiency** reflected by absent and, in the end-stage phase, reversed end-diastolic flow (EDF) in the UA.
- ❑ **Reduced fetal MCA-PI** is a consequence of vasodilatation, the so called '**brain-sparing effect**'. This represents a hemodynamic response to fetal hypoxemia, via direct vascular sensing of oxygen tension in the cerebral circuit, and in other vascular beds a consequent redistribution of fetal cardiac output occurs preferentially to the coronary arteries and adrenal glands.

Doppler velocimetry

Alterations in the ductus venosus flow velocity waveform, especially **absent or reversed a-wave**, are caused by ***progressive dilatation of the ductus venosus*** isthmus in order to increase the blood flow toward the heart, in an attempt to compensate for extreme oxygen deprivation. Others consider that absent or reversed a-wave in the ductus venosus is a consequence of **increased intra-atrial pressure** due to high cardiac afterload (increased vascular placental resistance) and/or a direct effect of **fetal acidemia on myocardial** cell function.

ISUOG Recommendations

- ❖ Fetal size alone is not sufficient to identify FGR, unless AC or EFW is below the 3rd percentile (GRADE OF RECOMMENDATION: C).
- ❖ A drop in fetal growth velocity, i.e. drop in AC or EFW of > 2 quartiles or > 50 percentiles (e.g. from 70th percentile to or below 20th percentile), should alert the physician to possible FGR (GRADE OF RECOMMENDATION: C).
- ❖ Doppler velocimetry of the uteroplacental and fetoplacental circulations may be used to distinguish between SGA and FGR (GOOD PRACTICE POINT).
- ❖ Multimodal assessment is recommended for the evaluation of pregnancies with suspected FGR. cCTG or BPP scoring should be used in combination with Doppler velocimetry (GRADE OF RECOMMENDATION: A).

Definition of early-onset and late-onset fetal growth restriction

- The distinction between early and late FGR is usually based on diagnosis before or after 32 weeks' gestation.
- Although UA Doppler evaluation seems to discriminate better than gestational age between the two phenotypes of FGR with regards to their association with pre-eclampsia and adverse perinatal outcome, 32 weeks seems to be the optimal gestational-age cut-off at diagnosis and provides a reasonable classification of the two FGR phenotypes.
- The criteria proposed by an international Delphi consensus represent the most recognized definition of FGR

Table 1 Main clinical characteristics of early- and late-onset fetal growth restriction (FGR)

<i>Characteristic</i>	<i>Early-onset FGR</i>	<i>Late-onset FGR</i>
Main clinical challenge	Management	Detection
Prevalence	30%	70%
Gestational age at manifestation	< 32 weeks	≥ 32 weeks
Ultrasound findings	Fetus may be very small	Fetus not necessarily very small
Doppler velocimetry	Spectrum of Doppler alterations that involves umbilical artery, middle cerebral artery and ductus venosus	Cerebral blood-flow redistribution
Biophysical profile	May be abnormal	May be abnormal
Hypertensive disorders of pregnancy	Frequent	Not frequent
Placental histopathological findings	Poor placental implantation, spiral artery abnormalities, maternal vascular malperfusion	Less specific placental findings, mainly altered diffusion
Perinatal mortality	High	Low
Maternal cardiovascular hemodynamic status	Low cardiac output, high peripheral vascular resistance	Less marked maternal cardiovascular findings

Table 2 Definitions for early- and late-onset fetal growth restriction (FGR) in absence of congenital anomalies, based on international Delphi consensus

<i>Early FGR:</i> <i>GA < 32 weeks, in absence of congenital anomalies</i>	<i>Late FGR:</i> <i>GA ≥ 32 weeks, in absence of congenital anomalies</i>
AC/EFW < 3 rd centile <i>or</i> UA-AEDF <i>Or</i> 1. AC/EFW < 10 th centile <i>combined with</i> 2. UtA-PI > 95 th centile <i>and/or</i> 3. UA-PI > 95 th centile	AC/EFW < 3 rd centile <i>Or at least two out of three of the following</i> 1. AC/EFW < 10 th centile 2. AC/EFW crossing centiles > 2 quartiles on growth centiles* 3. CPR < 5 th centile <i>or</i> UA-PI > 95 th centile

*Growth centiles are non-customized centiles. AC, fetal abdominal circumference; AEDF, absent end-diastolic flow; CPR, cerebroplacental ratio; EFW, estimated fetal weight; GA, gestational age; PI, pulsatility index; UA, umbilical artery; UtA, uterine artery. Reproduced from Gordijn *et al.*¹⁶.

Early-onset fetal growth restriction

- Early FGR is particularly associated with malperfusion of the placenta, so-called ‘**placental insufficiency**’.
- Chronic ischemia : excessive sFlt-1 release : elevated sFlt-1/PlGF ratio :hypertensive disorders of pregnancy.
- **Elevated Doppler UA-PI** typically precedes a cascade of Doppler alterations, fetal heart rate changes and BPP modifications, with end-stage cardiovascular deterioration caused by severe hypoxemia followed by acidosis.
- ***Uterine artery, UA and MCA Doppler abnormalities represent early changes*** in early FGR and may be present for many weeks before severe cardiovascular and metabolic deterioration occurs.
- Although absent **UA-EDF represents a progressive deterioration** of uteroplacental function, it still precedes critical fetal deterioration, and the progression to reversed UA-EDF might be slow.
- The late deterioration in early FGR characterized by severe placental insufficiency is reflected by reversal of the EDF in the UA, and worsening generalized cardiovascular and metabolic failure reflected by alterations in the **ductus venosus (absent or reversed a-wave)**.
- This cardiovascular deterioration might precede or occur in parallel with the alteration of the STV, eventually manifesting as abnormal BPP score, spontaneous repetitive decelerations on CTG(NST) and stillbirth.

ISUOG Recommendations

- Early FGR should be monitored and managed in **tertiary-level units** with multidisciplinary management by neonatology and maternal–fetal medicine specialists is indicated.
- **Multimodality assessment**, including CTG and UA, MCA and ductus venosus Doppler evaluation, is recommended.
- When cCTG is available, STV should be the main parameter assessed.
- **Monitoring should be scheduled based on the severity of FGR and alterations in UA Doppler.**
- Delivery should be based on biophysical assessments or maternal indication, as follows:
 - At any gestational age: presence of maternal indication (e.g. severe pre-eclampsia, HELLP syndrome) or obstetric emergency requiring delivery;
 - 24 + 0 to 25 + 6 weeks: personalized management;
 - $\geq 26 + 0$ weeks, deliver if any of the following is present:
 - Spontaneous repeated persistent unprovoked fetal heart rate decelerations.
 - Altered BPP (score ≤ 4);
 - 26 + 0 to 28 + 6 weeks: deliver if **ductus venosus** a-wave is at or below baseline or STV < 2.6 ms;
 - 29 + 0 to 31 + 6 weeks: deliver if **ductus venosus** a-wave is at or below baseline or STV < 3.0 ms;
 - 32 + 0 to 33 + 6 weeks (permitted after 30 + 0 weeks): deliver if **UA-EDF is reversed** or STV < 3.5 ms
 - $\geq 34 + 0$ weeks (permitted after 32 + 0 weeks): deliver if **UA-EDF is absent** or STV < 4.5 ms
- Corticosteroid prophylaxis is recommended if delivery is planned before 34 + 0 weeks of gestation
- Elective Cesarean delivery is recommended if one or more of the following is present: abnormal cCTG STV, ductus venosus Doppler alteration, absent or reversed UA-EDF, altered BPP, maternal indication.

Late-onset fetal growth restriction

- Late FGR is characterized by milder and more aspecific placental lesions and/or alteration in oxygen and nutrient diffusion.
- Consequently, alterations in UA Doppler and venous districts are rare and fail to identify the vast majority of late-FGR cases or to predict adverse outcome in these fetuses. Several studies have found an [association between MCA vasodilatation \(i.e. reduction in MCA-PI\) or the alteration of its ratio with UA-PI and poorer perinatal outcome](#).
- The rationale for using the ratios of MCA-PI and UA-PI (CPR and UCR) is that they can identify subtle changes between placental and cerebral blood-flow perfusion that may not be appreciated by evaluation of a single parameter.
-
- The biophysical abnormalities that characterize late FGR include alteration of fetal breathing, decreased amniotic fluid volume and loss of fetal heart rate reactivity on conventional CTG. However, in fetuses with late FGR, it seems that BPP becomes abnormal only shortly before stillbirth, and therefore, it is not useful in the determination of monitoring intervals.
- The pathophysiology of late FGR is still not completely understood and this may determine a lower identification rate of fetuses exposed to growth restriction near term. Moreover, fetuses near term seem to have reduced tolerance to hypoxemia, possibly because of their relatively high metabolic rate, compared with fetuses at an earlier gestation.
- **Frequent monitoring of pregnancies with late FGR is warranted in the same way as for those with early FGR.**

Late-onset fetal growth restriction

How to monitor

- At present, MCA-PI and its ratios to UA-PI are the most important Doppler parameters in the surveillance of late FGR.
- In the presence of UA-PI > 95th percentile, monitoring at least once or twice a week is indicated.
- In FGR pregnancies after 34 + 0 weeks of gestation, the median interval between a low MCA-PI and stillbirth was ≤ 5 days, suggesting that, if delivery has not been indicated by that time, twice-weekly Doppler surveillance may be required after 34 weeks.
- Almost 90% of stillbirths occur within 1 week of a normal BPP score in the presence of cerebral vasodilatation, suggesting that BPP may have poor value in determining the frequency of fetal monitoring.
- Considering the fact that some concerns have been raised regarding the interobserver reliability of MCA-PI measurement, when alteration in MCA-PI, CPR or UCR is encountered, the measurement should be confirmed within 24 h to avoid false-positive results, especially when timing of delivery is based on this finding¹⁰¹

Recommendations

- In pregnancies with late FGR, delivery should be based on biophysical assessments or maternal indication as follows:
 - At any gestational age, deliver if one of the following is present:
 - Spontaneous repeated persistent unprovoked fetal heart rate decelerations (**GOOD PRACTICE POINT**);
 - Altered BPP (score ≤ 4) (**GOOD PRACTICE POINT**);
 - Maternal indication (e.g. severe pre-eclampsia, HELLP syndrome) or obstetric emergency requiring delivery (**GOOD PRACTICE POINT**);
 - cCTG STV < 3.5 ms at 32 + 0 to 33 + 6 weeks and < 4.5 ms at $\geq 34 + 0$ weeks (**GOOD PRACTICE POINT**);
 - Absent or reversed UA-EDF (**GOOD PRACTICE POINT**);
 - 36 + 0 to 37 + 6 weeks: deliver if UA-PI $> 95^{\text{th}}$ percentile or AC/EFW $< 3^{\text{rd}}$ percentile (**GOOD PRACTICE POINT**);
 - 38 + 0 to 39 + 0 weeks: deliver if there is evidence of cerebral blood-flow redistribution or any other feature of FGR (**GOOD PRACTICE POINT**).
- In the absence of contraindications, induction of labor is indicated (**GOOD PRACTICE POINT**).
- During labor, continuous fetal heart rate monitoring is recommended (**GOOD PRACTICE POINT**).

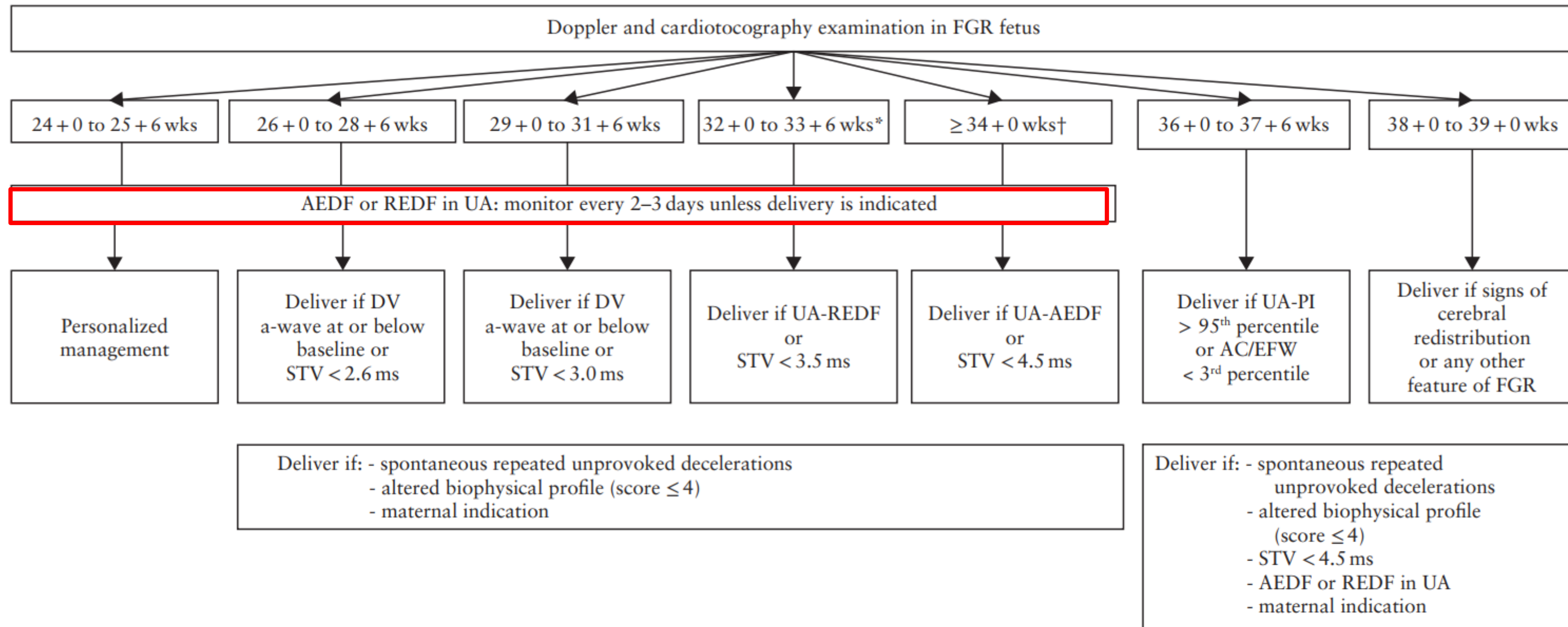


Figure 2 Recommended management of pregnancies with fetal growth restriction (FGR), based on computerized cardiotocography and Doppler findings. *Permitted after 30 + 0 weeks. †Permitted after 32 + 0 weeks. AC, fetal abdominal circumference; AEDF, absent end-diastolic flow; DV, ductus venosus; EFW, estimated fetal weight; PI, pulsatility index; REDF, reversed end-diastolic flow; STV, short-term variation; UA, umbilical artery; wks, gestational weeks.

Considerations in Doppler velocimetry

There is no universal agreement on which indices, thresholds and/or reference ranges to use.

A recent study evaluating the 10 most-cited articles providing reference ranges for MCA-PI, UA-PI and cerebroplacental ratio (CPR), found wide discrepancies in Doppler reference values that accounted for a variability of up to 50% in the 5th percentile cut-off value of MCA-PI at term.

Wide discrepancies have been reported in reference ranges used for biometry, Doppler parameters and birth weight, even at national level in centers with high expertise in the management of FGR, that might significantly impact the diagnosis and management of FGR.

There is no uniformity in Doppler indices that are used, especially in research studies. For example, cerebral blood-flow redistribution can be defined as MCA-PI below different percentile thresholds (5th or 10th percentile), Z-scores or multiples of the median (MoM), or it can be defined as umbilicocerebral ratio (UCR) or CPR above or below different percentile thresholds, Z-scores or MoM, respectively.

The Delphi consensus procedure identified CPR below the 5th percentile and UA-PI above the 95th percentile as Doppler criteria to define FGR.

The rationale behind the application of the ratios of MCA-PI and UA-PI (CPR and UCR), instead of the individual components, is that they have been shown to be more sensitive to fetal hypoxia and to be associated more strongly with adverse perinatal outcome.

CPR is reported in studies more frequently than is UCR. A recent study suggested that UCR may allow for better differentiation of cases in the abnormal range in early FGR, as compared with CPR.

Small-for-gestational age

- SGA is often considered as a constitutionally small fetus that is otherwise healthy;
- It is frequently the case that the SGA categorization is applied to a small baby that is structurally normal and has **normal Doppler findings**. In these cases, the adoption of customized growth charts has been suggested to reduce the proportion of SGA.
- However, there is evidence suggesting that SGA with normal fetoplacental Doppler can be associated with accelerated placental aging, signs of placental underperfusion, lower umbilical vein blood flow volume, altered maternal hemodynamics and greater incidence of Cesarean section for fetal distress compared with AGA fetuses.
- Such evidence poses the question as to whether there might be a subgroup of SGA fetuses that do in fact suffer from '**stunted**' fetal growth, which adapt to a poor nutritional environment and are not identified by standard biophysical diagnostic tools.

How to monitor SGA

- ❑ At the diagnosis of SGA, **fetal Doppler indices** (UA-PI, MCA-PI and their ratios) and uterine artery Doppler should be evaluated.
- ❑ In the case of late SGA (after 32 weeks), once uterine artery Doppler has been assessed at diagnosis, there is no need for uterine artery Doppler to be re-evaluated at each visit as, usually, it remains unchanged from diagnosis of SGA to delivery.
- ❑ **Fortnightly assessment of fetal growth is recommended.**
- ❑ Late-SGA fetuses with abnormal uterine artery PI at diagnosis, compared to those without, are more likely to progress to brain sparing, in other words 'cross over' to FGR, and this usually occurs at earlier gestational-age epochs.
- ❑ Even late-SGA fetuses with normal uterine artery PI can progress to brain sparing, albeit less frequently and 1– 2 weeks later than fetuses with abnormal uterine artery PI.

ISUOG Recommendations- SGA

- Fetal Doppler velocimetry should be performed both at the diagnosis of SGA and during follow-up.
- In case of late SGA, fortnightly assessment of fetal growth and weekly assessment of UA-PI, MCA-PI, CPR and UCR is recommended.
- When SGA has been identified, delivery should be planned from 38 + 0 weeks and the pregnancy should not exceed 39 + 0 weeks of gestation.
- Continuous fetal heart rate monitoring during labor is indicated.

Table 1. Intrauterine Growth Restriction Staging

Stage	UA		MCA		DV		UV		TV E/A	TR
	aPI	ARF	aPI	aPSV	aPI	RF	P	RF		
I	+		+							
II		+		+	+		+			
III						+		+	+	+

Stage I: abnormal (a) UA PI or MCA PI; stage II: umbilical artery absent/ reversed flow (ARF), elevated MCA PSV, UV pulsation (P), and abnormal DV PI (an absent DV A wave is considered an abnormal DV PI); stage III: DV RF, UA RF, TV E/A ratio of 1 or higher, and TR. The presence of any 1 abnormal parameter in a stage would place the fetus in that stage.

معیار های تشخیص IUGR:

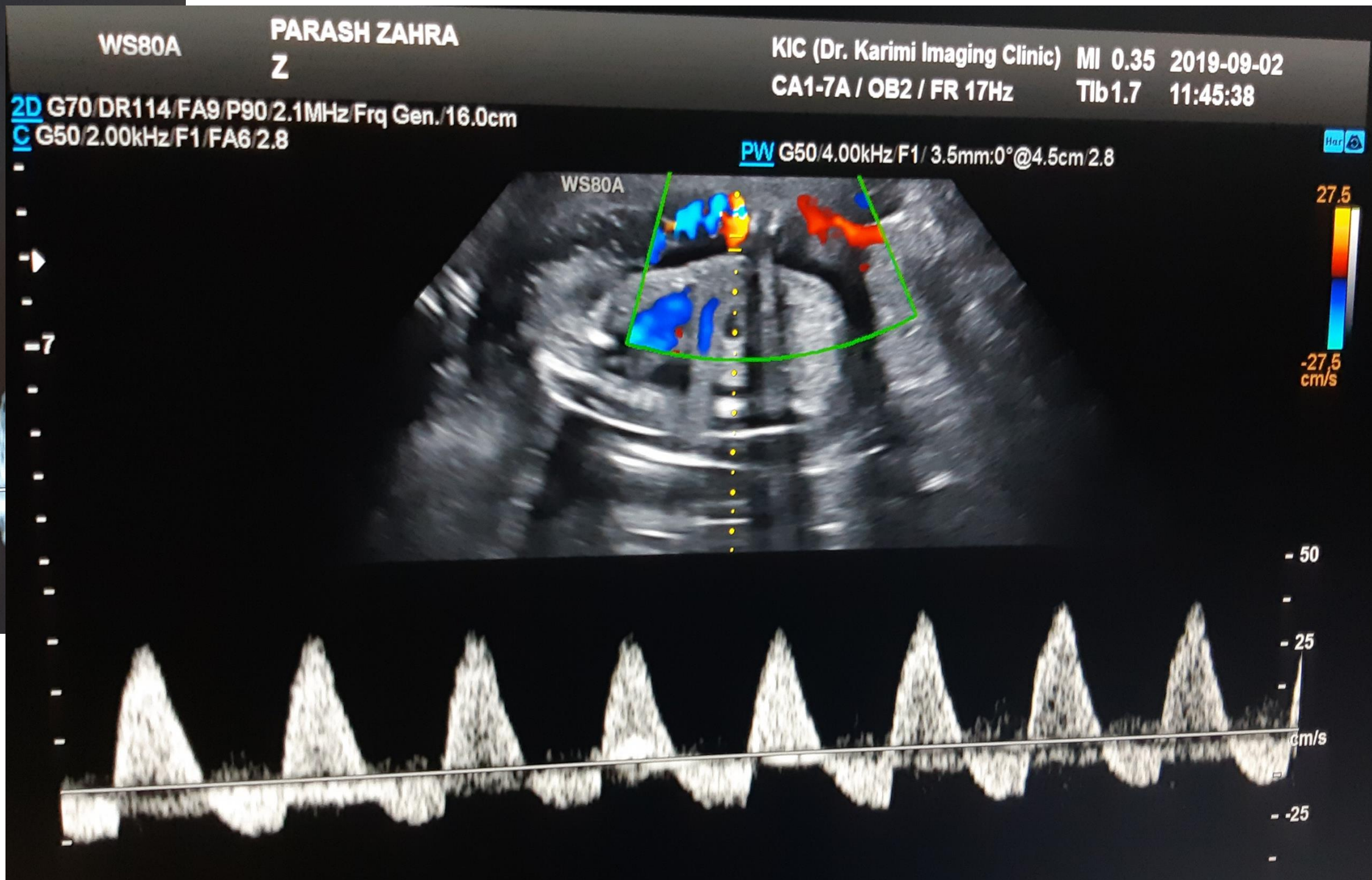
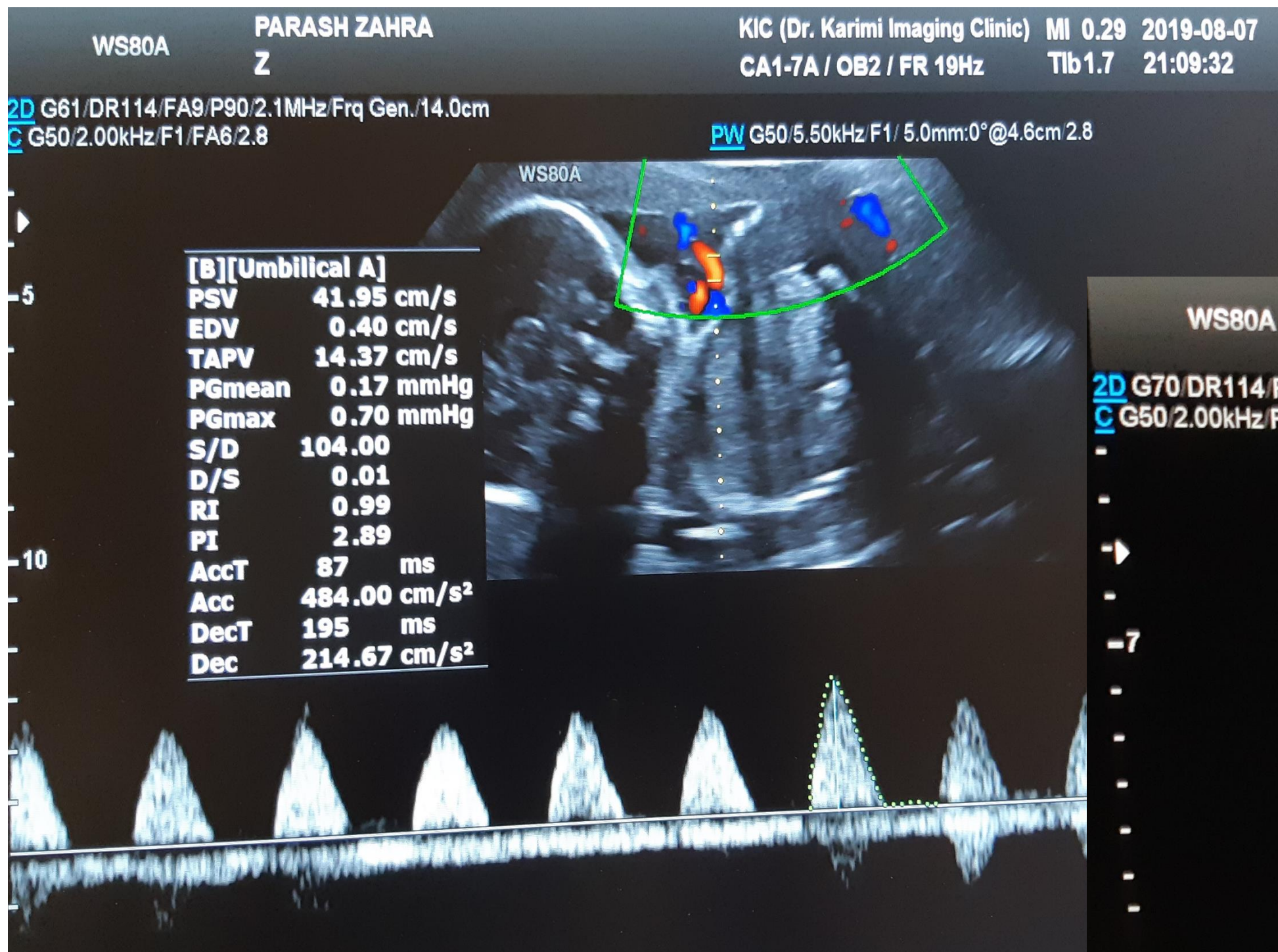
در سن بارداری کمتر از ۳۲ هفته	در سن بارداری مساوی یا بیشتر از ۳۲ هفته
- اندازه دور شکم (AC) یا وزن تخمینی جنین کمتر از ۳٪ یا فقدان جریان خون پایان دیاستولی (AEDF) در داپلر شریان ناف - اندازه دور شکم (AC) یا وزن تخمینی جنین کمتر از ۱۰٪ به همراه یکی از موارد زیر:	- اندازه دور شکم (AC) یا وزن تخمینی جنین کمتر از ۳٪ و یا - وجود حداقل دو معیار زیر:
o PI متوسط شریان رحمی بیش از ۹۵٪ یا o PI متوسط شریان ناف بیش از ۹۵٪	o اندازه دور شکم (AC) یا وزن تخمینی جنین کمتر از ۱۰٪ o کاهش صدک اندازه دور شکم و وزن تخمینی جنین به میزان دو چارک o نسبت PI شریان مغزی میانی به PI شریان نافی (CPR) کمتر از ۵٪ یا PI شریان نافی بیش از ۹۵٪

مدیریت IUGR

مرحله	پاتوفیزیولوژی	معیار (هر کدام از)	ارزیابی (حداقل فاصله زمانی)	زمان ختم بارداری	نوع زایمان
I IUGR	کوچی شدید و یا نارسایی خفیف جفت	EFW<3rd centile CPR<P5 UA PI>P95 MCA PI<P5 UtA PI>P95	- سونوگرافی بیومتری هر دو هفته یکبار - داپلر هر هفته یکبار - بیوفیزیکال پروفایل دوبار در هفته	۳۷ هفته	القای زایمان
II IUGR	نارسایی شدید جفت	UA AEDV Reverse AoI	- داپلر و بیوفیزیکال پروفایل دو بار در هفته - NST روزانه	۳۴ هفته	سزارین. در صورت زایمان واژینال، مانیتور دائم در تمام مراحل
III IUGR	زوال پیشرفته جنین، احتمال کم اسیدوز جنین	UA REDV DV PI>p95	- داپلر، بیوفیزیکال پروفایل و cCTG حداقل هر ۴۸-۲۴ ساعت	۳۲ هفته	سزارین
IV IUGR	احتمال بالای اسیدوز جنین و خطر بالای مرگ جنین	DV reverse a flow cCTG<3ms FHR decelerations	مانیتورینگ مستمر ضربان قلب جنین	۲۶ هفته	سزارین

EFW: Estimated Fetal Weight
CPR: Cerebroplacental Ratio
UA: Umbilical Artery
PI: Pulsatility Index
MCA: Middle Cerebral Artery

ADF: Absent Diastolic Flow
AEDF: Absent End Diastolic Flow
DV: Dactus Venosus
UtA: Uterine Artery
AoI: Aortic isthmus Index

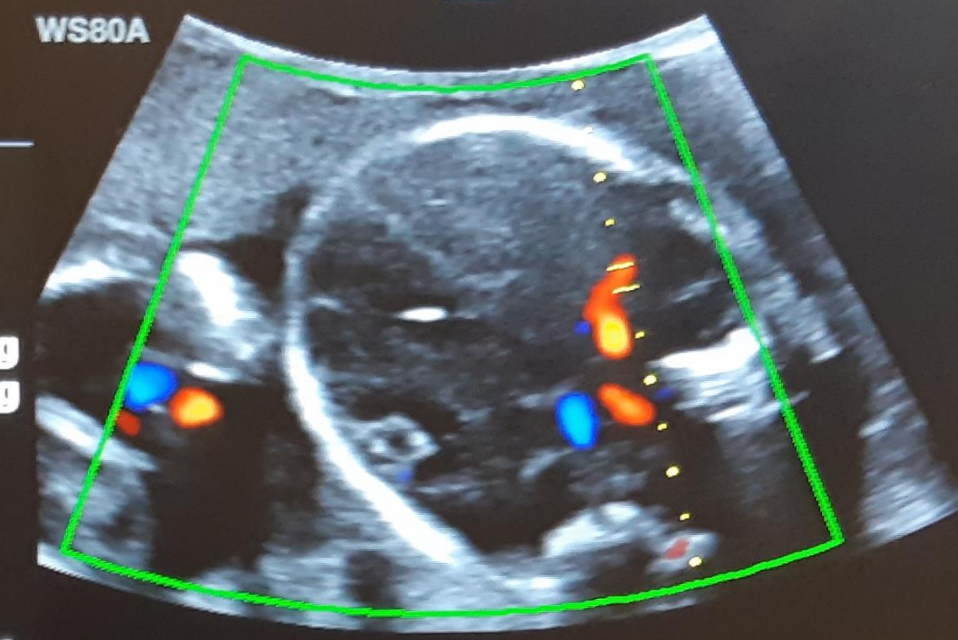


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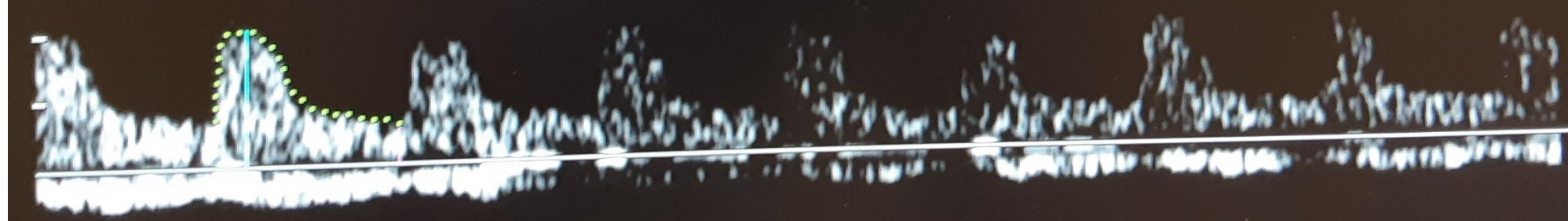
KIC (Dr. Karimi Imaging Clinic) MI 0.40 2019-08-07
CA1-7A / OB2 / FR 18Hz Tlb1.6 21:10:42

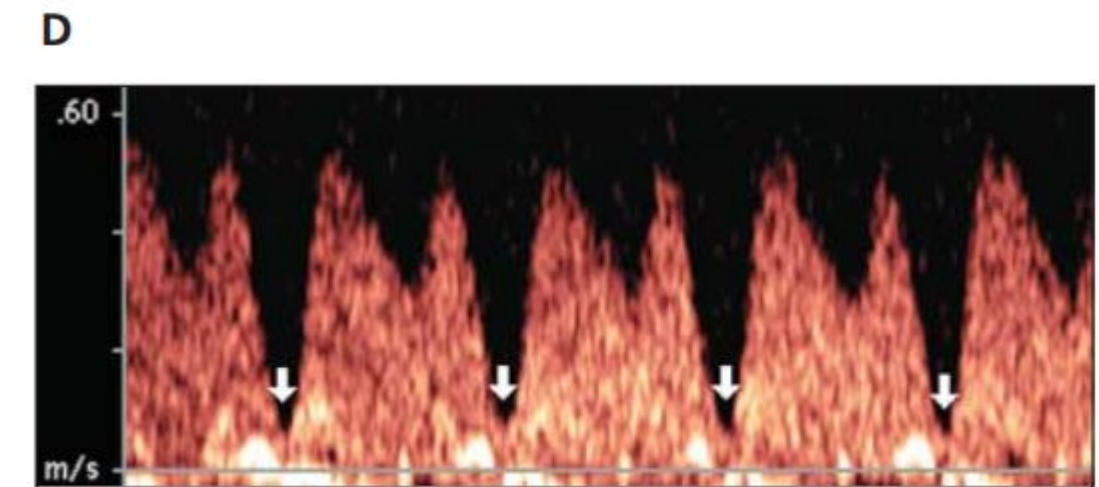
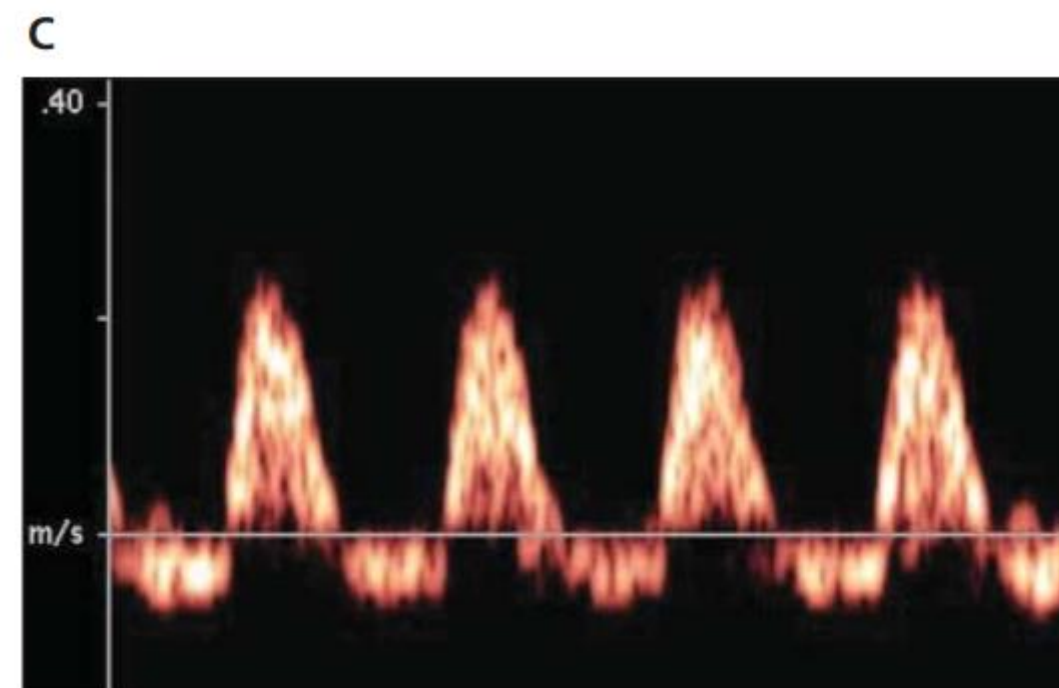
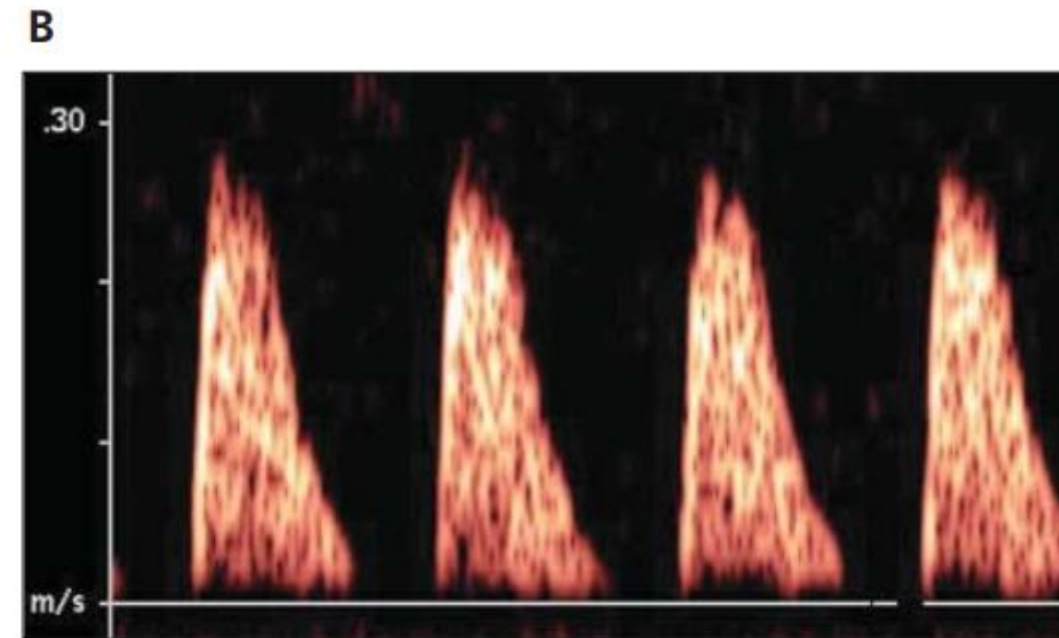
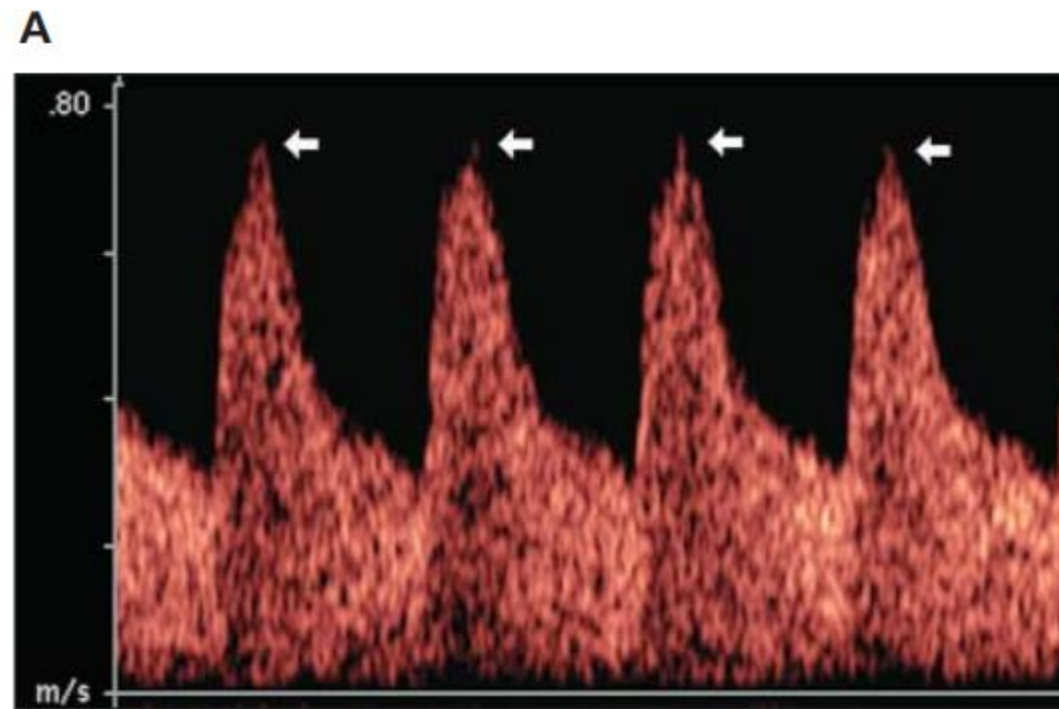
2D G61/DR114 FA9 P90 2.1MHz Frq Gen./6.0cm
C G50 2.00kHz F1/FA6 2.8

PW G50 4.00kHz F1/ 2.5mm:0°@4.5cm 2.8 **PG10**



[B][Mid Cereb A]	
PSV	25.81 cm/s
EDV	7.63 cm/s
TAPV	14.97 cm/s
PGmean	0.11 mmHg
PGmax	0.27 mmHg
S/D	3.38
D/S	0.30
RI	0.70
PI	1.21
AccT	63 ms
Acc	407.58 cm/s ²
DecT	276 ms
Dec	93.57 cm/s ²

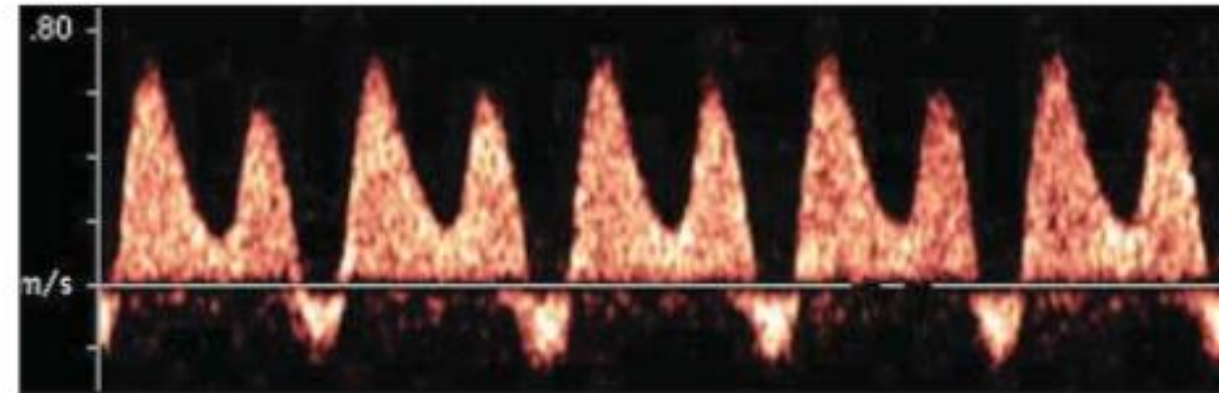




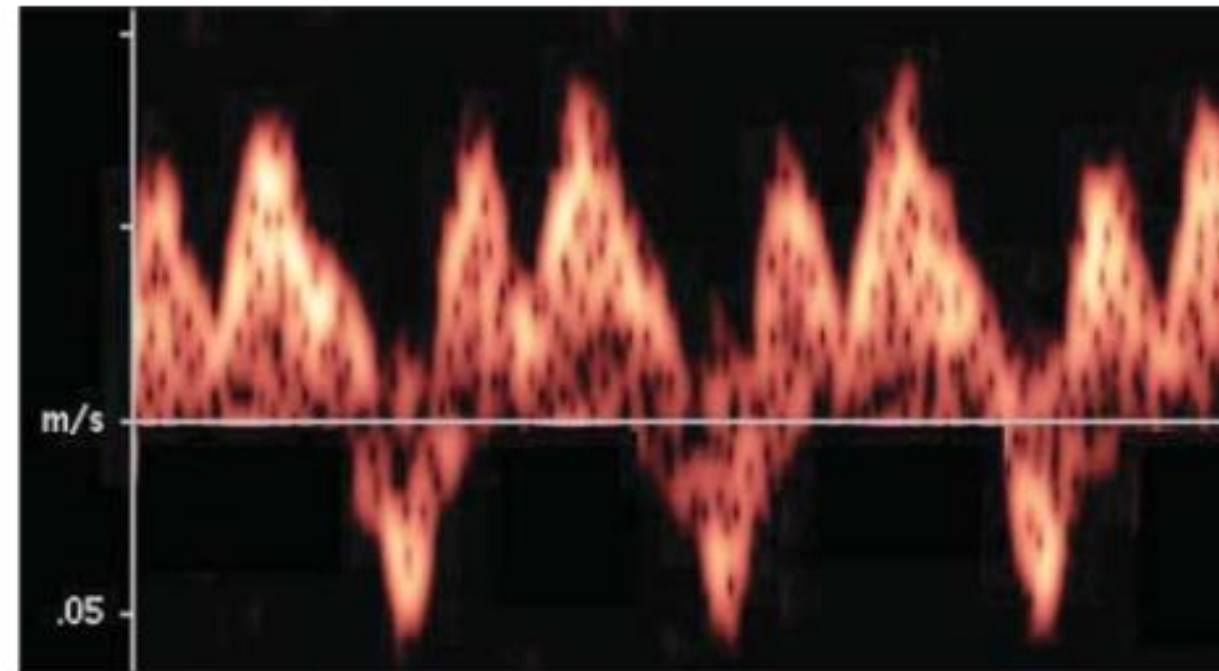
A, Flow velocity waveforms of the MCA. These waveforms were obtained in an IUGR fetus at 27 weeks' gestation. The arrows point to the MCA PSV, which is abnormal (76 cm/s). B and C, Absent and reversed flow in the UA, respectively. D, Abnormal DV Doppler flow. The arrows point to the A wave recorded at the atrial contraction. When there is a low A wave, the PI is abnormal. The presence of 1 of these findings characterizes stage II.

Figure 3. The presence of 1 of the following findings characterizes stage III: **A**, DV RF; **B**, UV RF; and **C**, an abnormal TV waveform (E/A ratio >1).

A



B



C



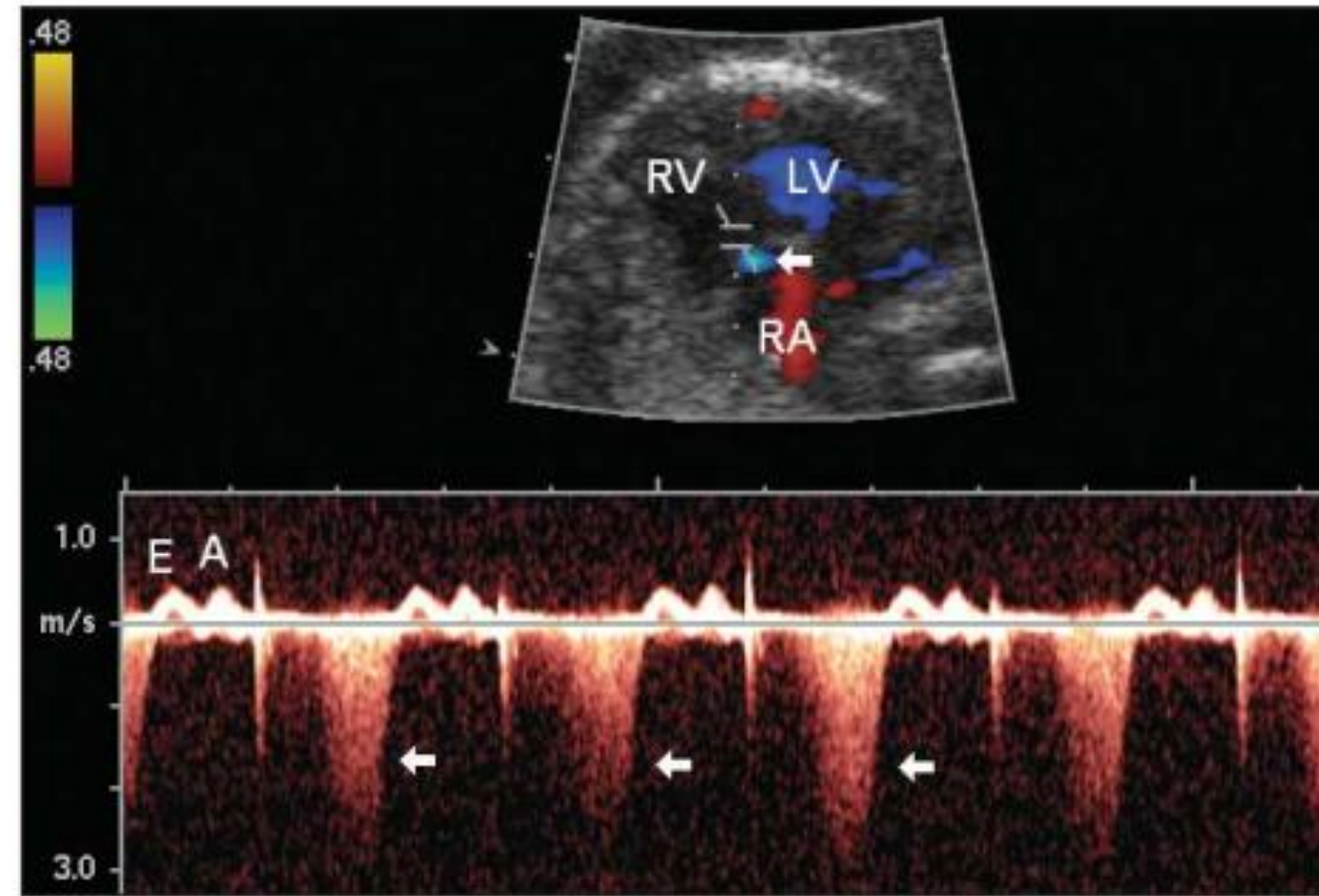
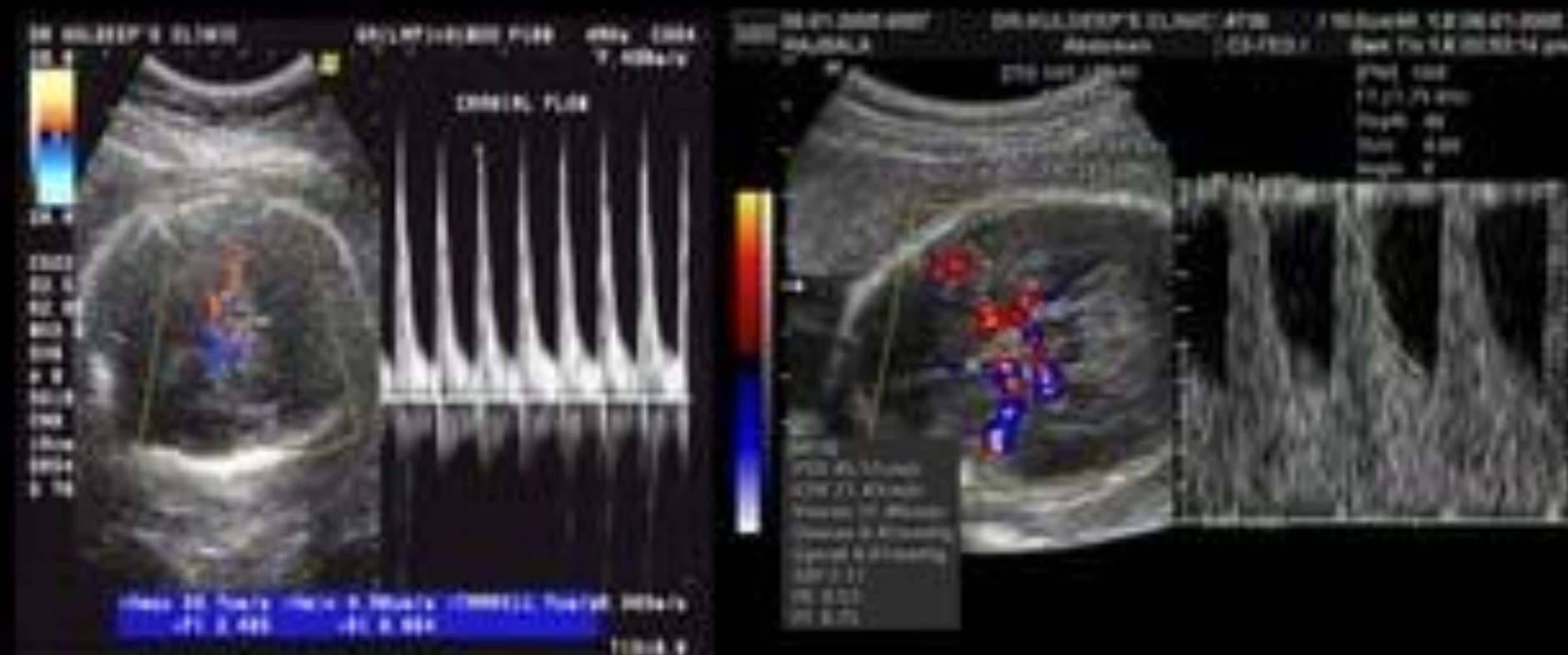


Figure 4. Tricuspid regurgitation evidenced by color Doppler ultrasonography (arrow). The pulsed Doppler image shows the TV waveforms above the baseline, with the E and A waveforms, and diastolic regurgitation (arrows) below the baseline. LV indicates left ventricle; RA, right atrium; and RV, right ventricle.

NORMAL & ABNORMAL WAVEFORM



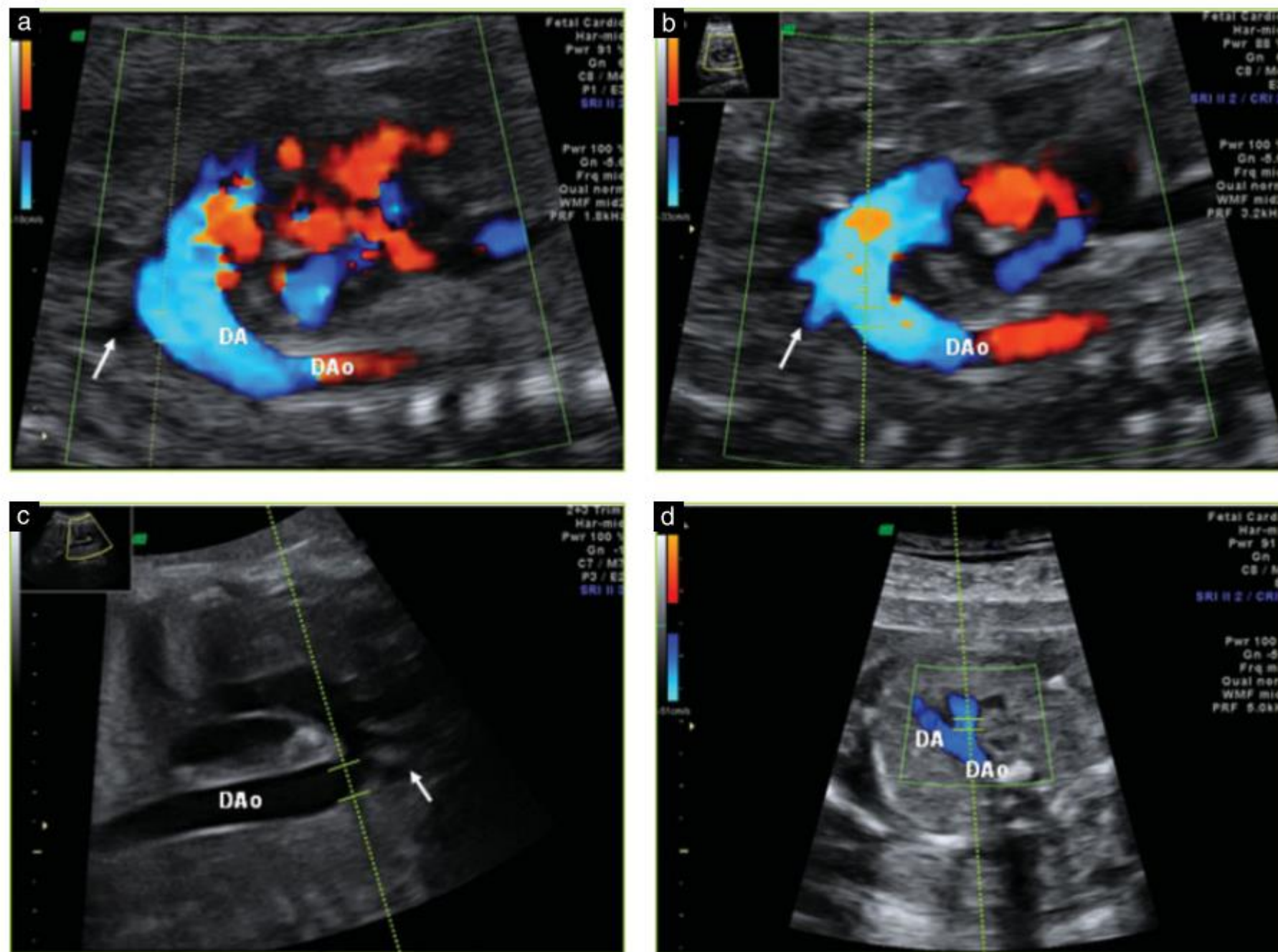


Figure 1 Longitudinal (a–c) and cross-sectional (d) imaging planes demonstrating the aortic isthmus with correct cursor placement for pulsed-wave Doppler interrogation. The arrow indicates the left subclavian artery. DA, ductus arteriosus; DAo, descending aorta.

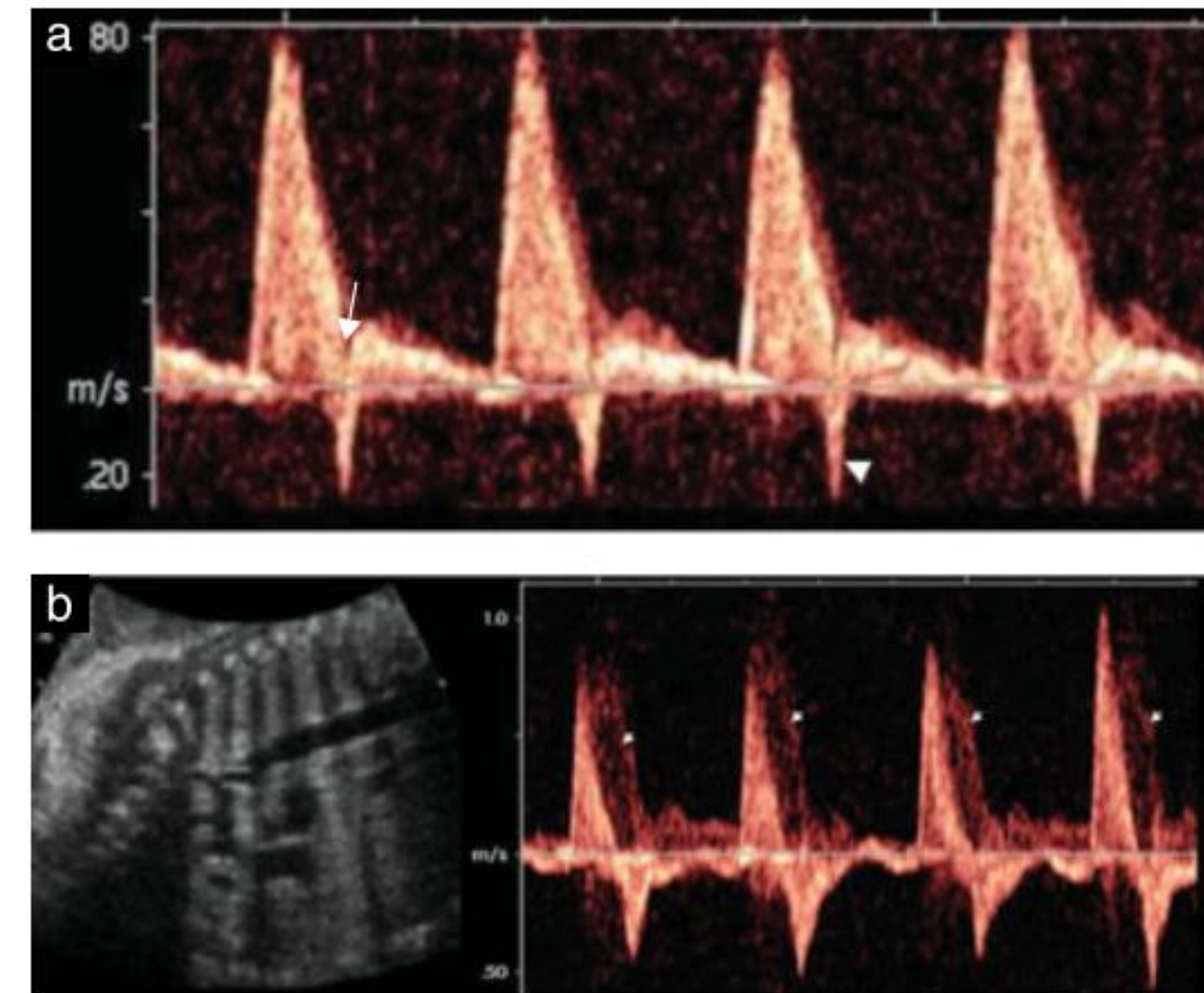


Figure 3 Typical normal (a) and abnormal (b) aortic isthmus Doppler flow velocity waveforms in the third trimester. In (a), the arrow points to the incisura and the arrowhead points to the brief retrograde flow at end-systole. In (b), small arrowheads point to the ductus arteriosus blood flow velocity waveforms in the background. Note that the aortic isthmus flow is reversed in late systole and the whole of diastole (net flow is retrograde).

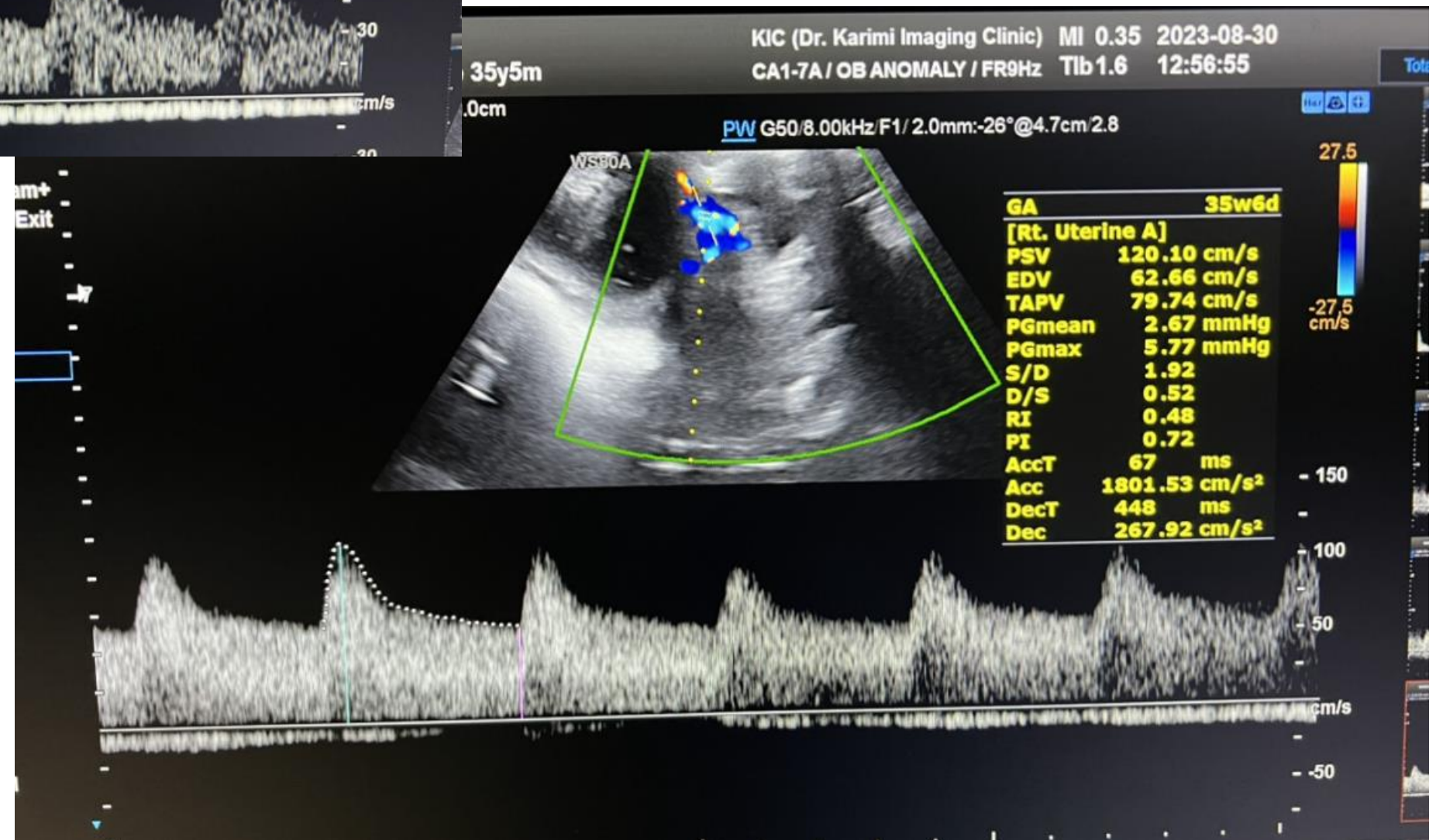
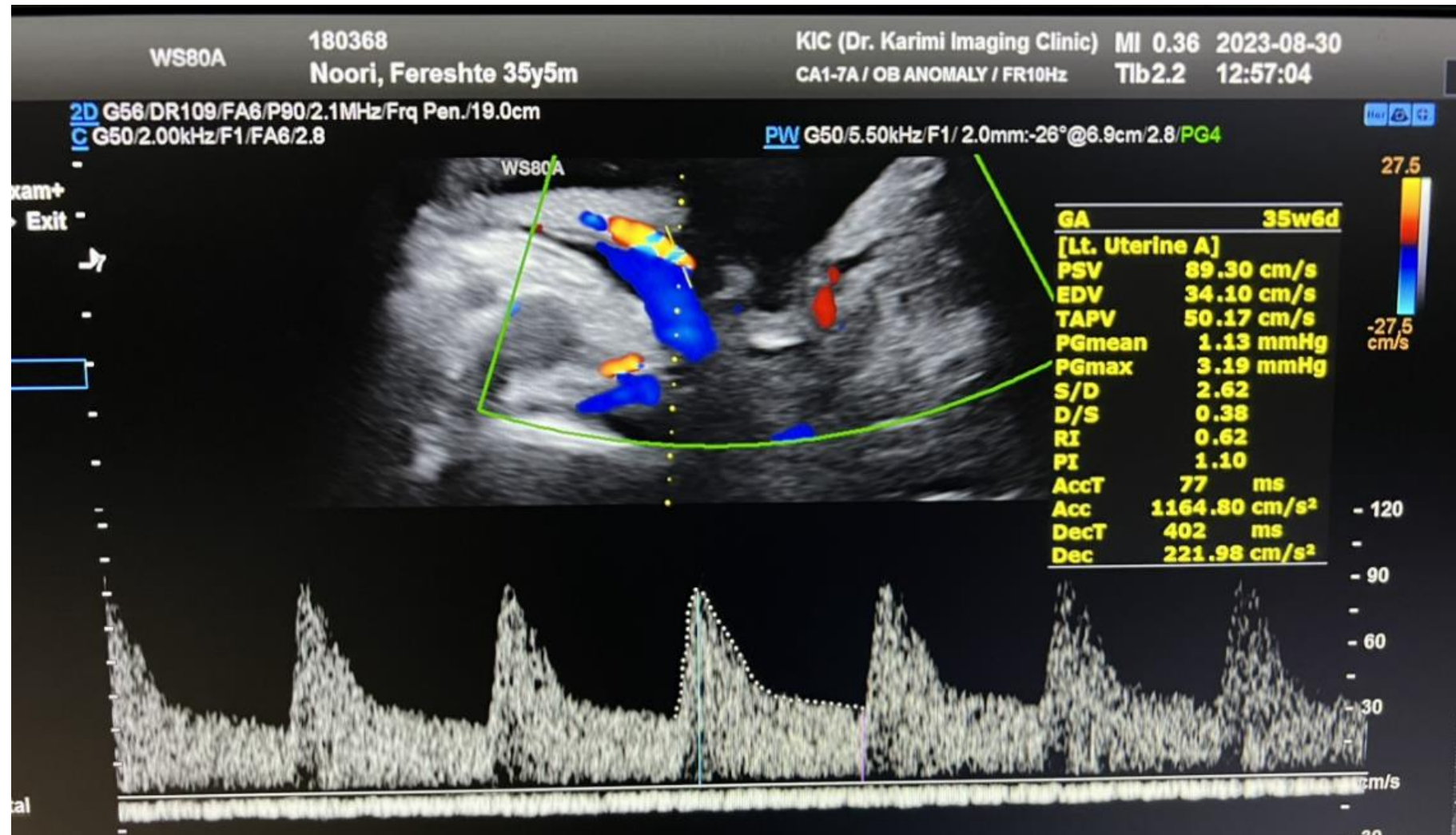
Ultrasound Report

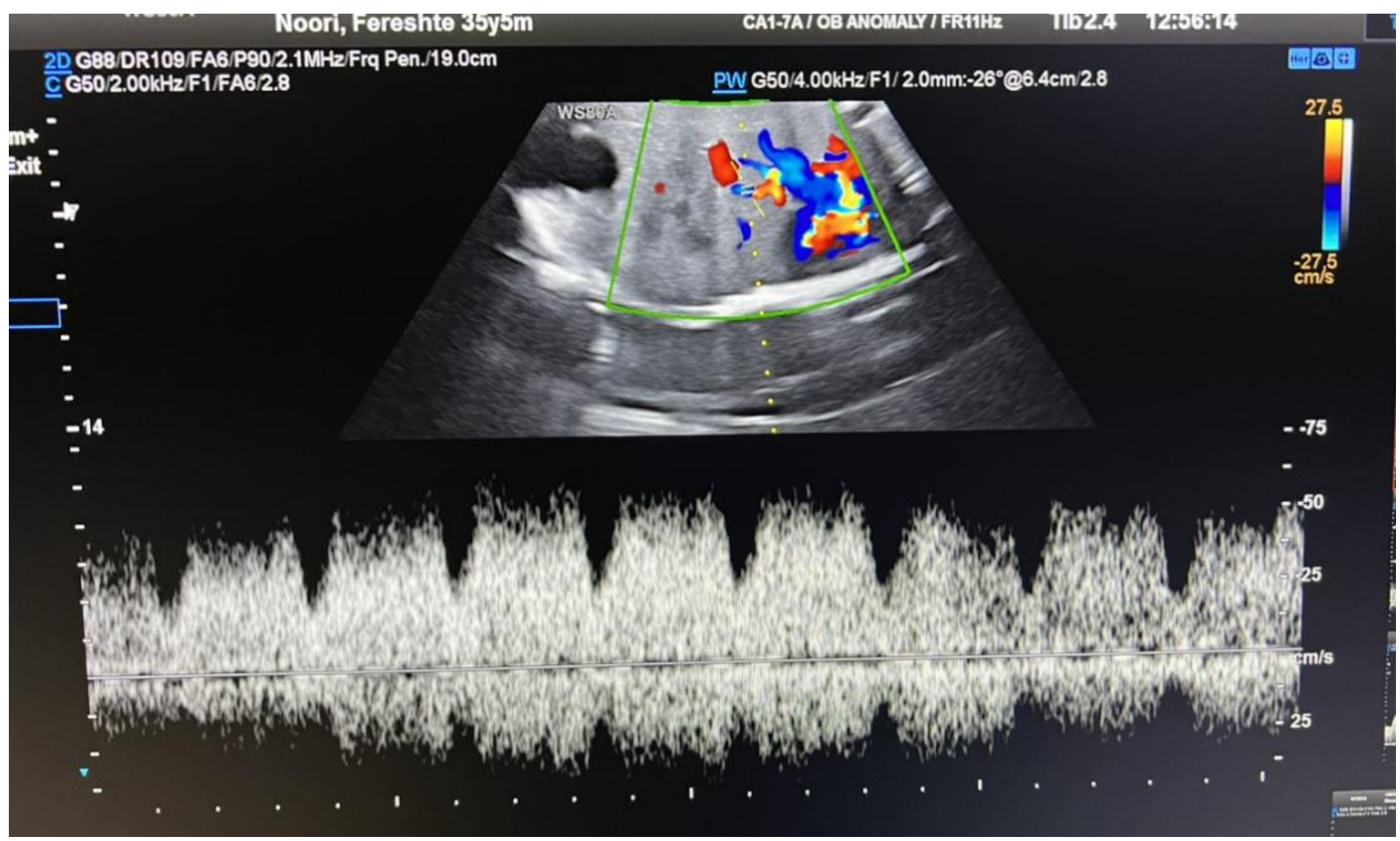
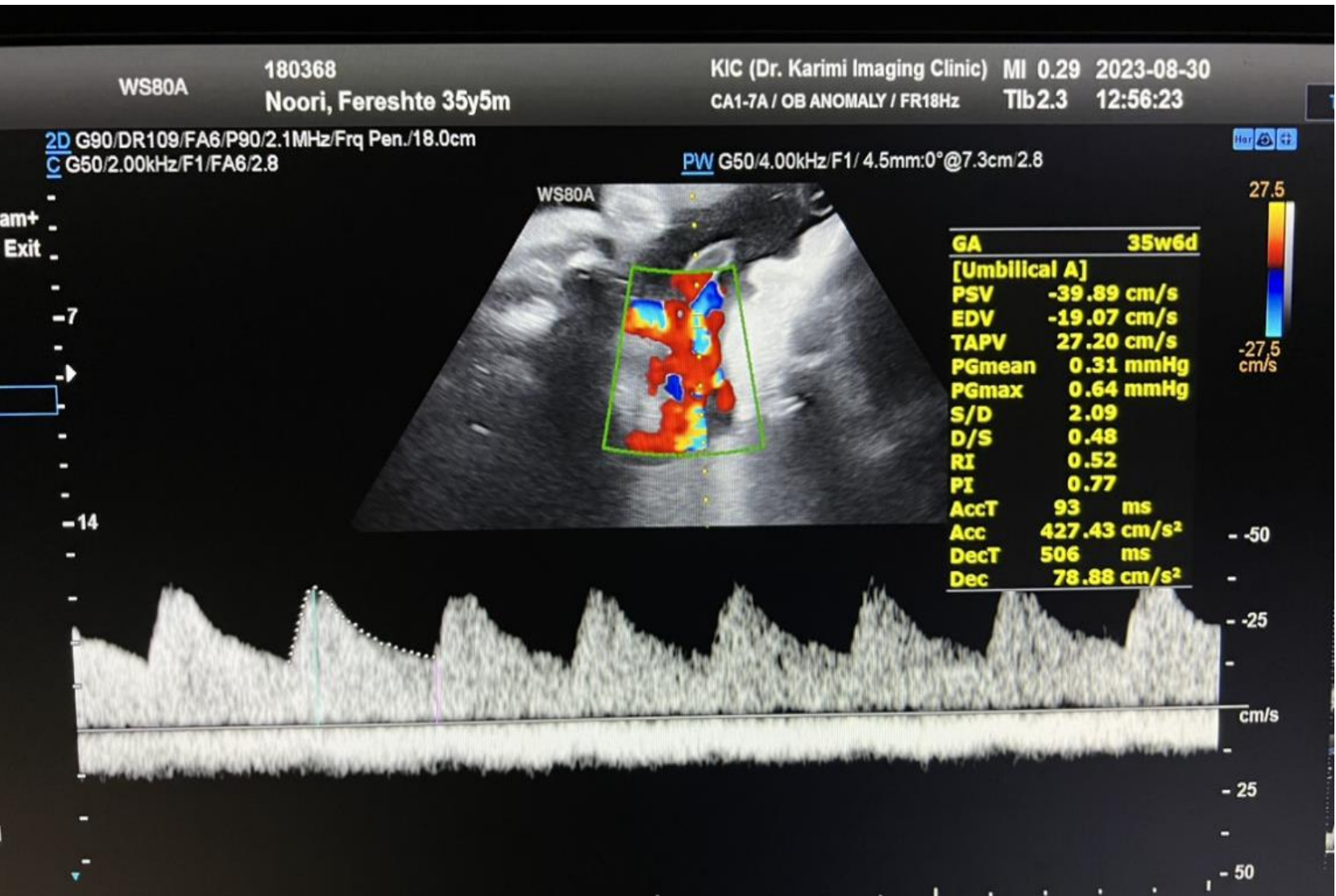
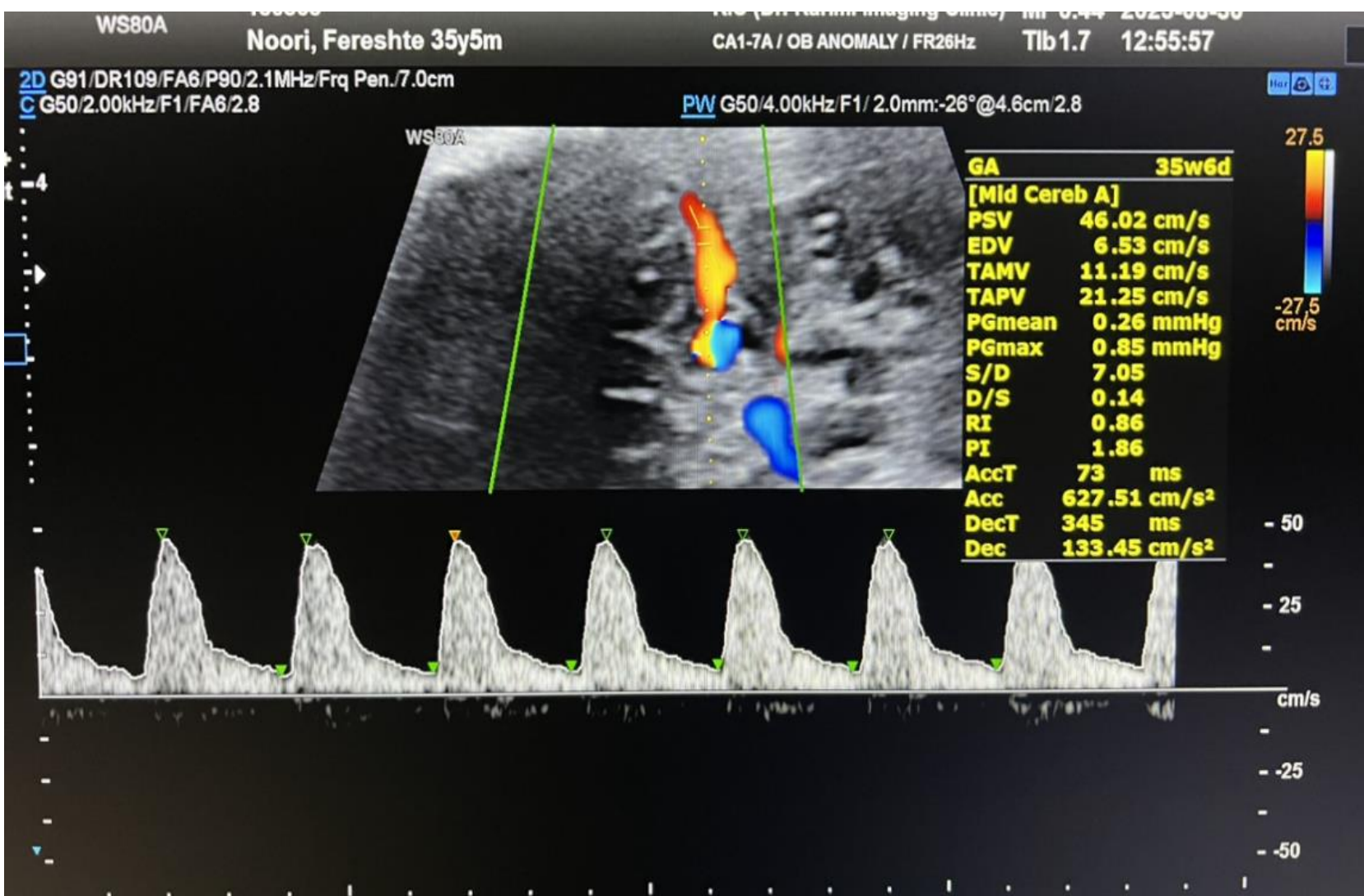
Name	Noori, Fereshta	ID	180368	Exam. Date	2023-08-30
Gender	Female	BirthDate	1988-03-21	Age	35yr 5m
Institute	KIC (Dr. Karimi Imagi...	Ref. Physician	äçÑóíó äõíñí		
Description	1550 T				

[OB]

EDD(GA)	2023-09-28	GA	35w6d	AUA	34w2d
EDD(AUA)	2023-10-09	Pctl. Criteria	EDD(GA)	EFW	2163g±324g
EFW Author	Hadlock3 (AC,FL,...	GA(EFW)	33w0d	Pctl.(EFW)	4.66*
SD(EFW)	-1.68*				

Fetal Biometry		Last	1	2	3	mm	GA		Pctl.	
BPD		89.69	89.69			mm	36w2d±22d	Hadlock	70.29	Hadlock
HC		323.78	323.78			mm	36w4d±18d	Hadlock	49.05	Hans...
AC		287.41	287.41			mm	32w5d±20d	Hadlock	1.65*	Hadlock
FL		62.78	62.78			mm	32w6d	Doubilet	0.61*	Hadlock
Fetal Long Bo...		Last	1	2	3	mm	GA		Pctl.	
HUM		57.06	57.06			mm	33w1d±20d	Jeanty	26.18	Jeanty
AFI		Last	1	2	3	mm	Last	1	2	3
Q1		52.72	52.72			mm	Q2	33.62	33.62	
Q3		43.01	43.01			mm	Q4	21.51	21.51	
AFI		150.86(57 ...	150.86			mm				





First-trimester uterine artery evaluation

1. Transabdominal technique

- Transabdominally, a mid-sagittal section of the uterus is obtained, and the cervical canal is identified.
- The probe is then moved laterally until the paracervical vascular plexus is seen.
- Color Doppler is turned on and the uterine artery is identified as it turns cranially, to make its ascent to the uterine body. Measurements are taken at the point before the uterine artery branches into the arcuate arteries.
- As the PSV decreases from the uterine to the arcuate arteries, a measurement of PSV < 5th centile (60 cm/s)⁷ should prompt the operator to verify carefully the placement of the sample volume.
- The same process is repeated on the contralateral side.

An alternative approach to obtain the Doppler signals using a cross-sectional plane has been described, and showed comparable values and equally good reproducibility when compared to the sagittal plane.

2. Transvaginal technique

- The woman should be asked to empty her bladder and should be placed in the dorsal lithotomy position.
- Transvaginally, the probe is placed in the anterior fornix. Similar to the transabdominal technique, the probe is moved laterally to visualize the paracervical vascular plexus, and the same steps are carried out in the same sequence as for the transabdominal technique.
- Care should be taken not to insonate the cervicovaginal artery (which runs in a cranial to caudal direction) or the arcuate arteries.

Second- and third-trimester uterine artery evaluation

1. Transabdominal technique

- Transabdominally, the probe is placed longitudinally in the lower lateral quadrant of the abdomen, angled medially in the parasagittal plane. Color flow mapping is useful to identify the uterine artery as it is seen crossing the external iliac artery.
- The uterine arteries usually run along each side of the uterus towards the fundus. To obtain the best angle of insonation, the position of the probe should be adjusted according to the orientation of the uterine artery.
- The sample volume is placed 1 cm downstream from this crossover point.
- In a small proportion of cases, the uterine artery branches before the intersection of the external iliac artery. In such cases, the sample volume should be placed on the uterine artery just before its bifurcation.
- The same process is repeated for the contralateral uterine artery.
- With advancing gestational age, the uterus usually undergoes dextrorotation. Thus, the left uterine artery does not run as lateral relative to the uterus as does the right

2. Transvaginal technique

- The woman should be asked to empty her bladder and should be placed in the dorsal lithotomy position.
- The probe is placed in the lateral fornix and the uterine artery identified, using color Doppler, at the level of the internal cervical os .

This should then be repeated for the contralateral uterine artery.

It should be remembered that reference ranges for uterine artery Doppler indices depend on the technique of measurement, so appropriate corresponding reference ranges should be used for transabdominal and transvaginal routes.

Note that, in women with congenital uterine anomaly, assessment of uterine artery Doppler indices and their interpretation is unreliable, since all published studies have been on women with (presumed) normal anatomy.

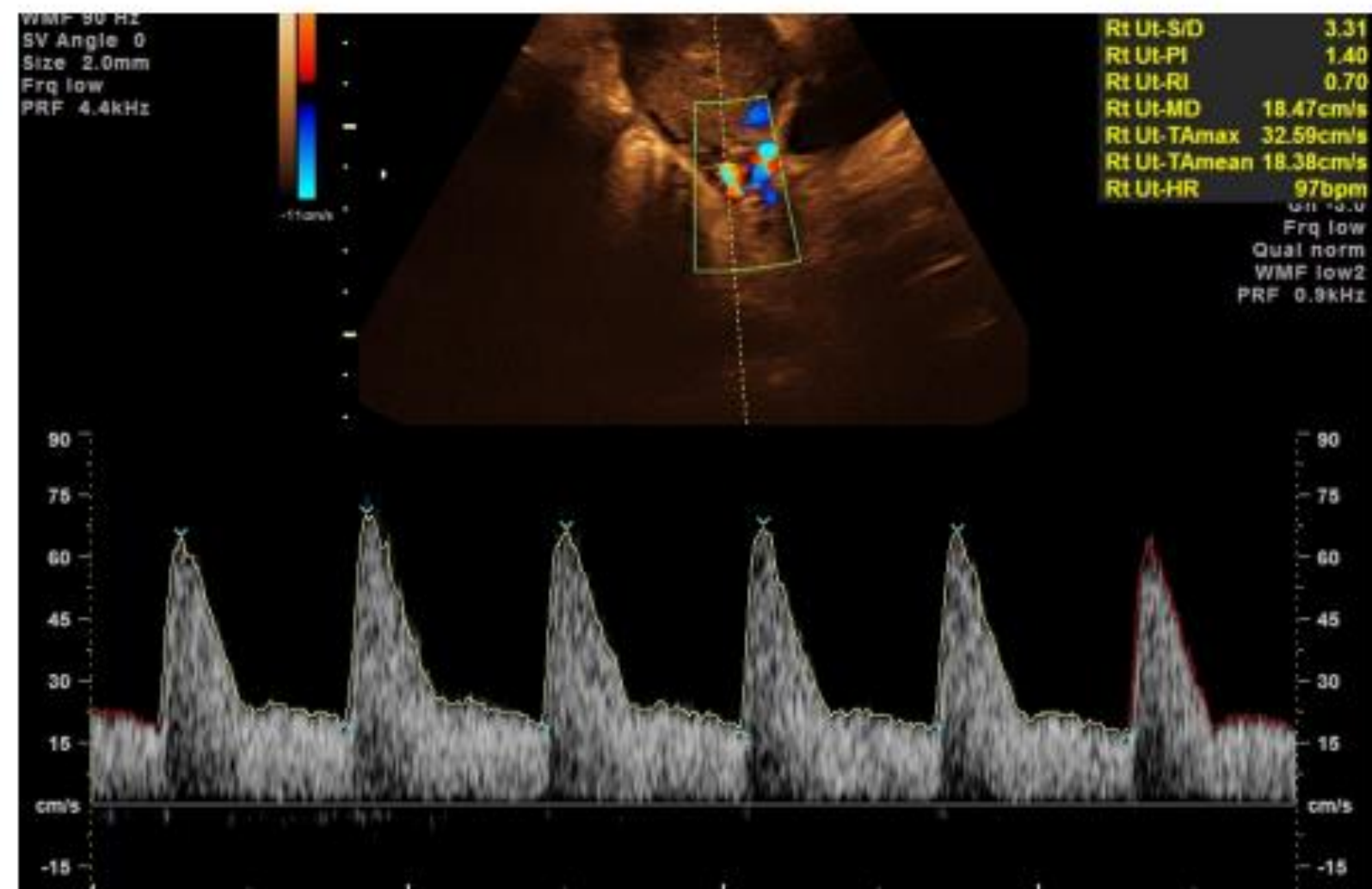


Figure 1 Waveform from uterine artery obtained transabdominally in first trimester.

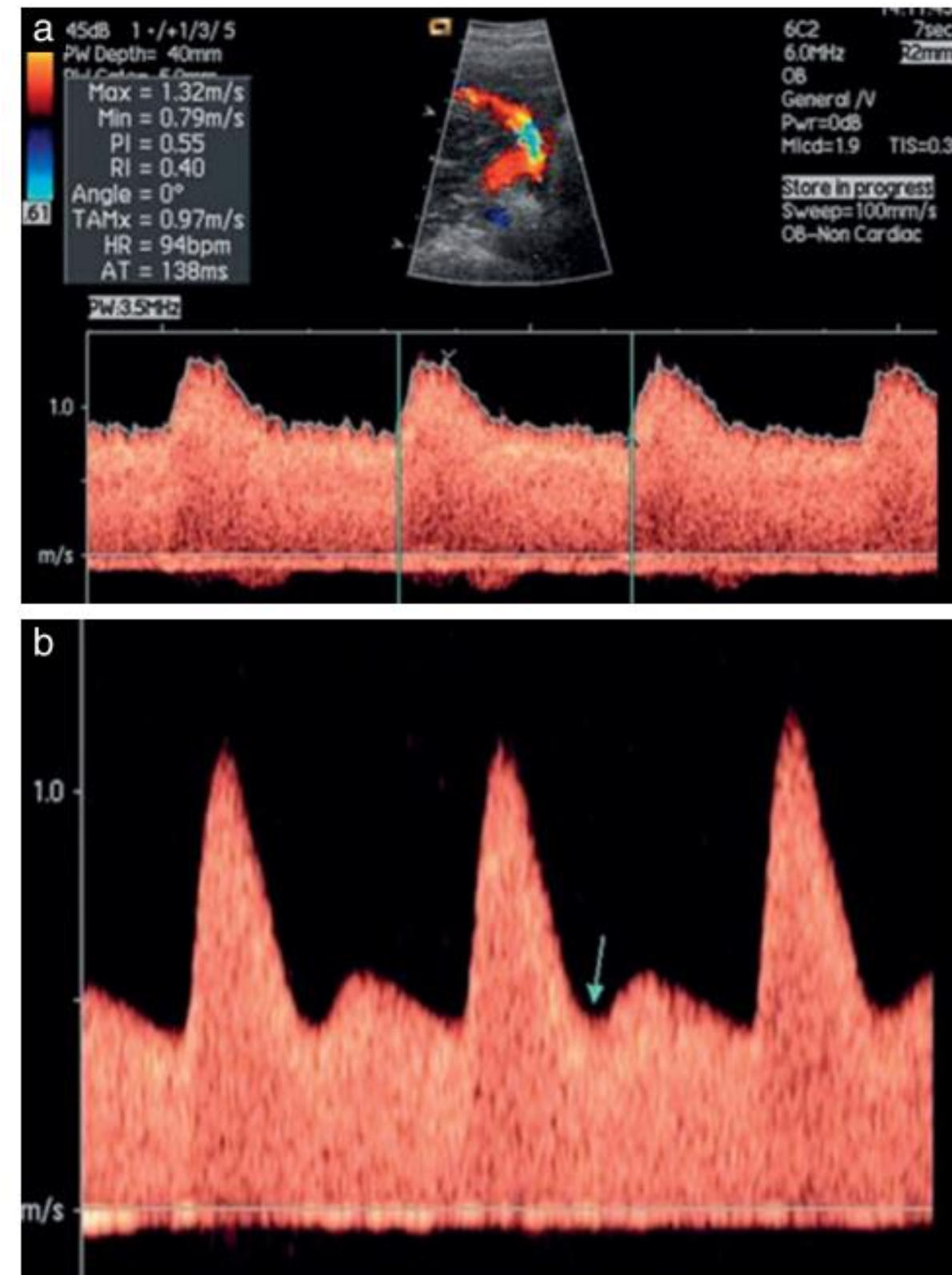
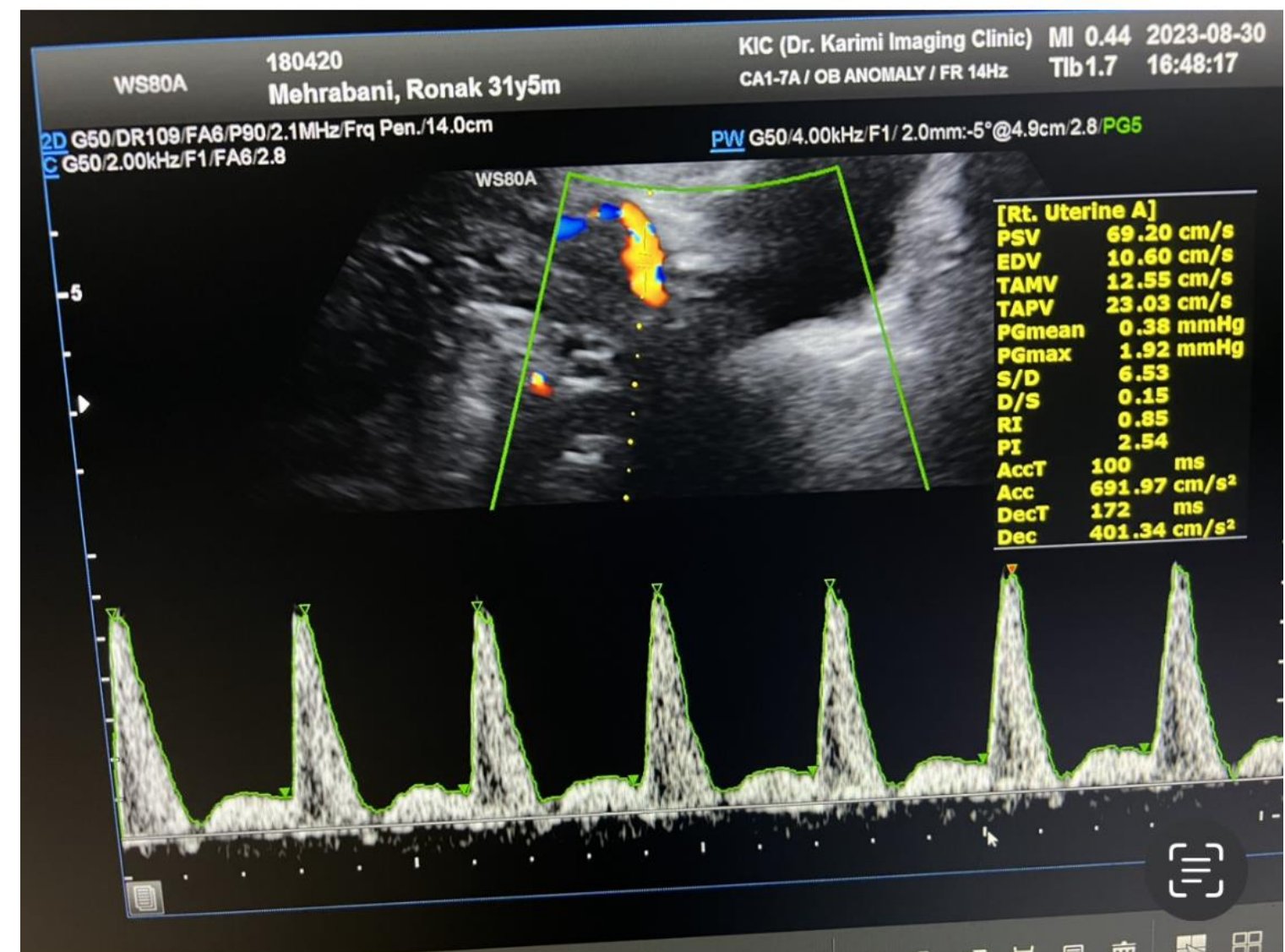
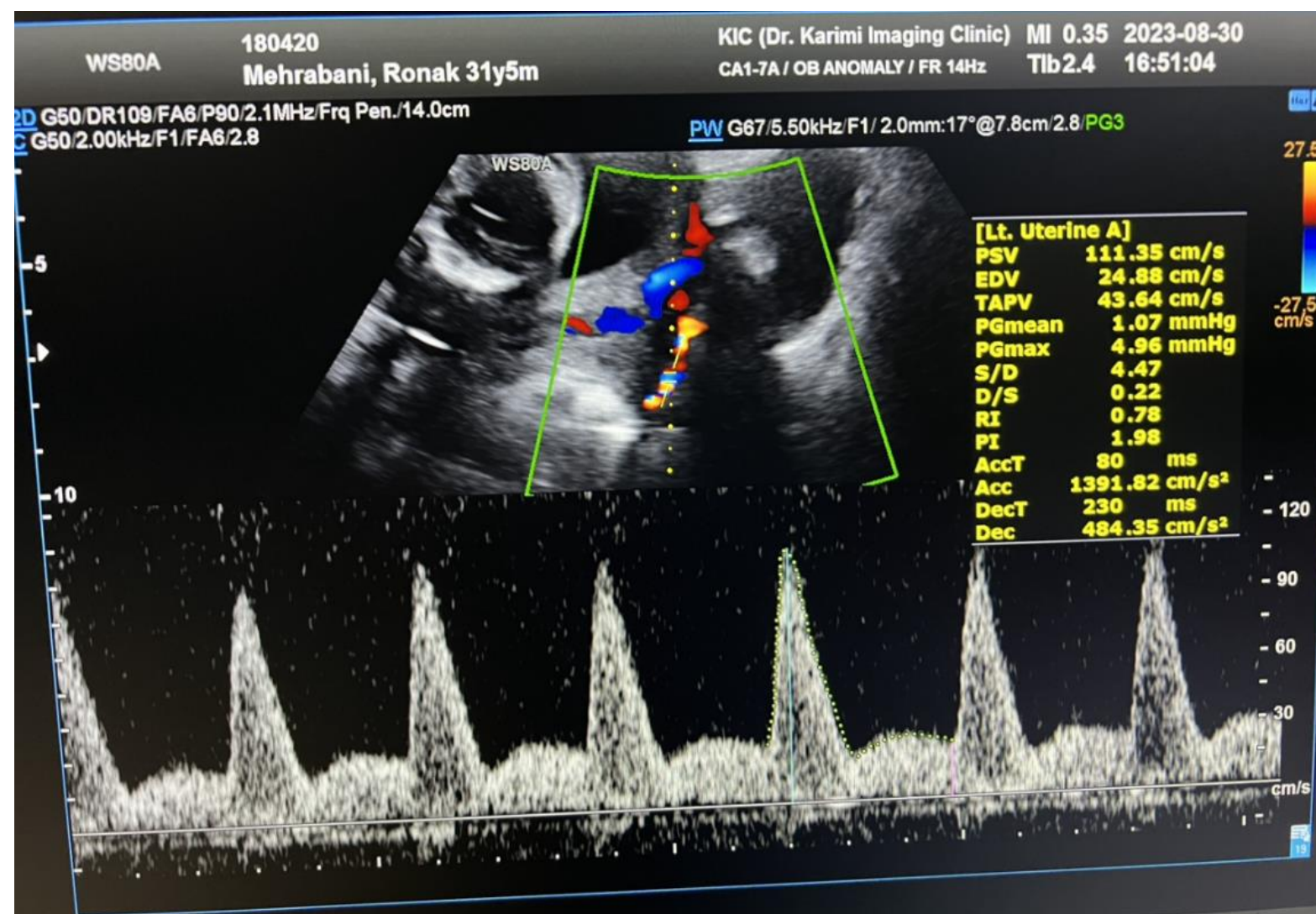


Figure 2 Waveforms from uterine artery obtained trans-abdominally in second trimester. Normal (a) and abnormal (b) waveforms; note notch (arrow) in Doppler signal in (b).



technique for obtaining umbilical artery Doppler waveforms

There is a significant difference in Doppler indices measured at the fetal end (intra-abdominal), in a free loop and at the placental end of the umbilical cord.

The impedance is highest at the fetal end, and absent/reversed EDV is likely to be seen first at this site.

For the sake of simplicity and consistency, by convention, measurements should be made in a **free cord loop**.

Note that, in multiple pregnancy, assessment of umbilical artery blood flow can be challenging, since there may be difficulty in assigning a cord loop to a particular fetus. It is therefore better to sample the umbilical artery just distal to the abdominal insertion of the umbilical cord.

However, the impedance there is higher than that in a free loop and that at the placental cord insertion, so appropriate reference charts are needed.

In a two-vessel cord, at any gestational age, the diameter of the single umbilical artery is larger than the arterial diameter would be if there were two arteries. Due to the different hemodynamics, the recorded velocity waveform in such cases should be interpreted with caution when using conventional reference ranges.

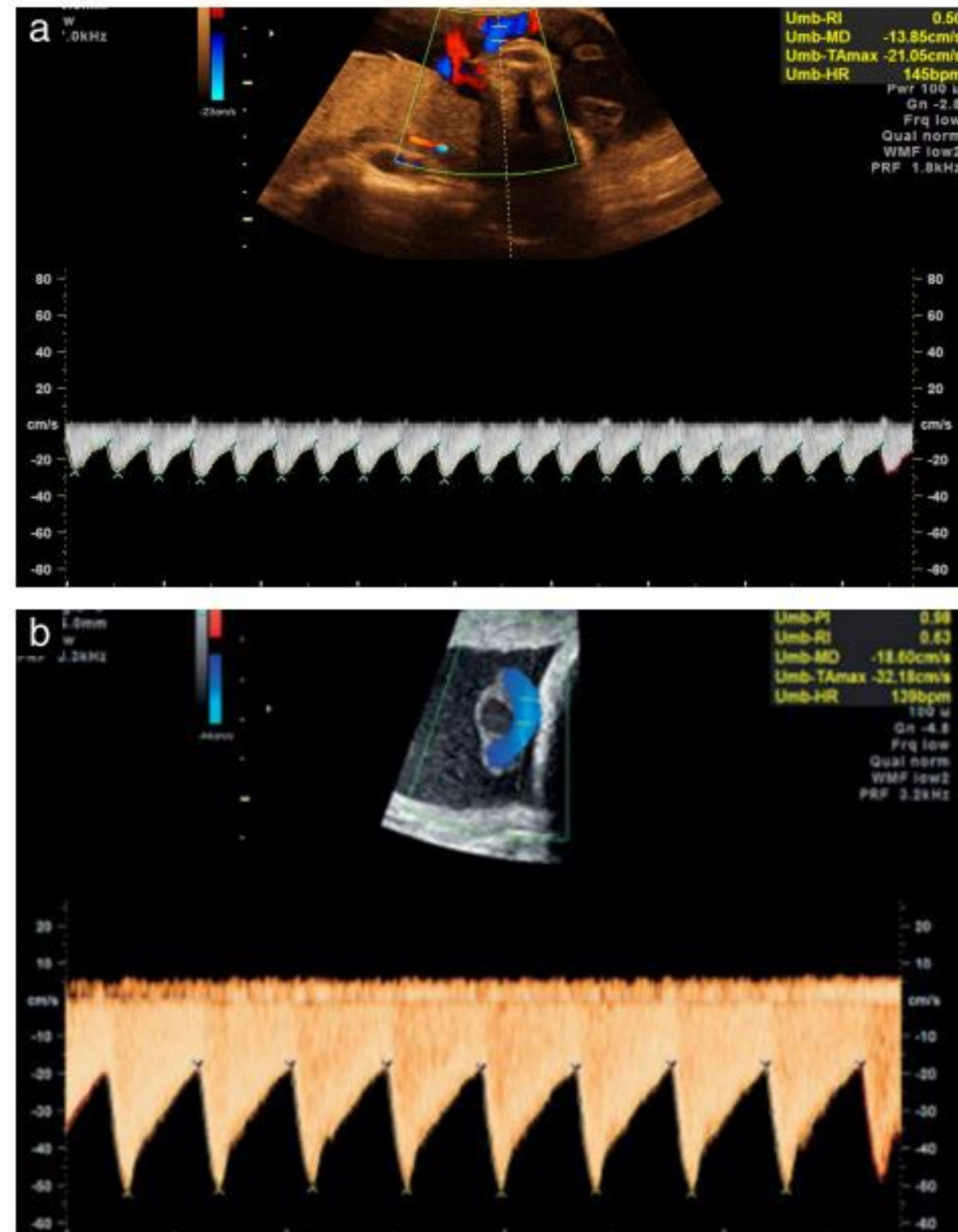


Figure 3 Examples of unacceptable (a) and acceptable (b) umbilical artery waveforms. The recording is improved by reducing the Doppler scale (i.e. reducing the pulse repetition frequency) to magnify the velocity recording on the screen, as well as adjusting the sweep speed to cover only three to nine consecutive waves.

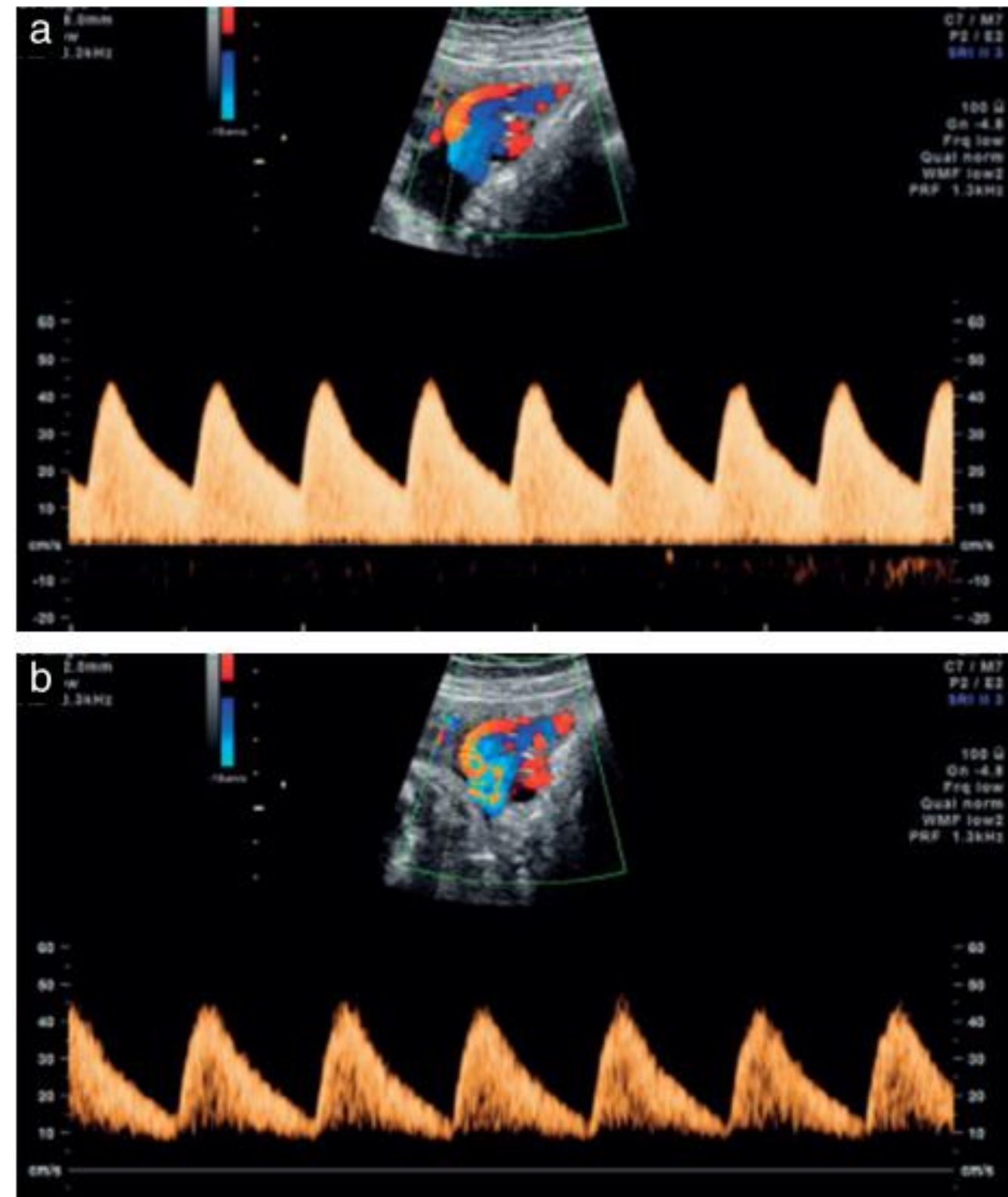


Figure 4 (a) Umbilical artery velocity waveform recorded with a low vessel wall filter setting showing normal flow and (b) a recording with apparently very low diastolic flow and absent flow signals at baseline, due to use of incorrect vessel wall filter, which is set too high, thereby concealing the low velocities along the zero line.

Technique for obtaining fetal middle cerebral artery Doppler waveforms?

- An axial section of the brain, including the thalami and the sphenoid bone wings, should be obtained and magnified.
- Color flow mapping should be used to identify the circle of Willis and the proximal MCA, just caudal to the transthalamic plane.
- The pulsed-wave Doppler gate should then be placed at the proximal third of the MCA, close to its origin in the internal carotid artery (the systolic velocity decreases with increasing distance from the point of origin of this vessel).
- The angle between the ultrasound beam and the direction of blood flow should be kept as close as possible to 0°.
 - Care should be taken to avoid any unnecessary pressure on the fetal head, as this may lead to increased PSV, decreased EDV and increased PI.
- At least three and fewer than 10 consecutive waveforms should be recorded. The highest point of the waveform is considered as the PSV (in cm/s).
- The PSV can be measured using manual calipers or autotrace. PI is commonly reported using autotrace measurement, but manual tracing is also acceptable. In fact, manual caliper placement was used in the seminal work investigating the value of MCA-PSV for non-invasive detection of fetal anemia.

The interobserver reliability of MCA-PI measurement is reported to be only moderate, with limited agreement between two observers.

The 95% interval of the PI differences between observers was +0.91 to –1.14 at the proximal sampling site of the near-field MCA.

In about 30% of cases, the PI difference between observers was greater than 0.517. Multiple measurements are recommended to assess the true value.

MCA-PSV measurements at the proximal site of the MCA in the near field are comparable to those obtained from the far-field vessel in clinical practice.

The far-field vessel may be chosen if obtaining an insonation angle of 0° is easier for the far-field than for the near-field MCA

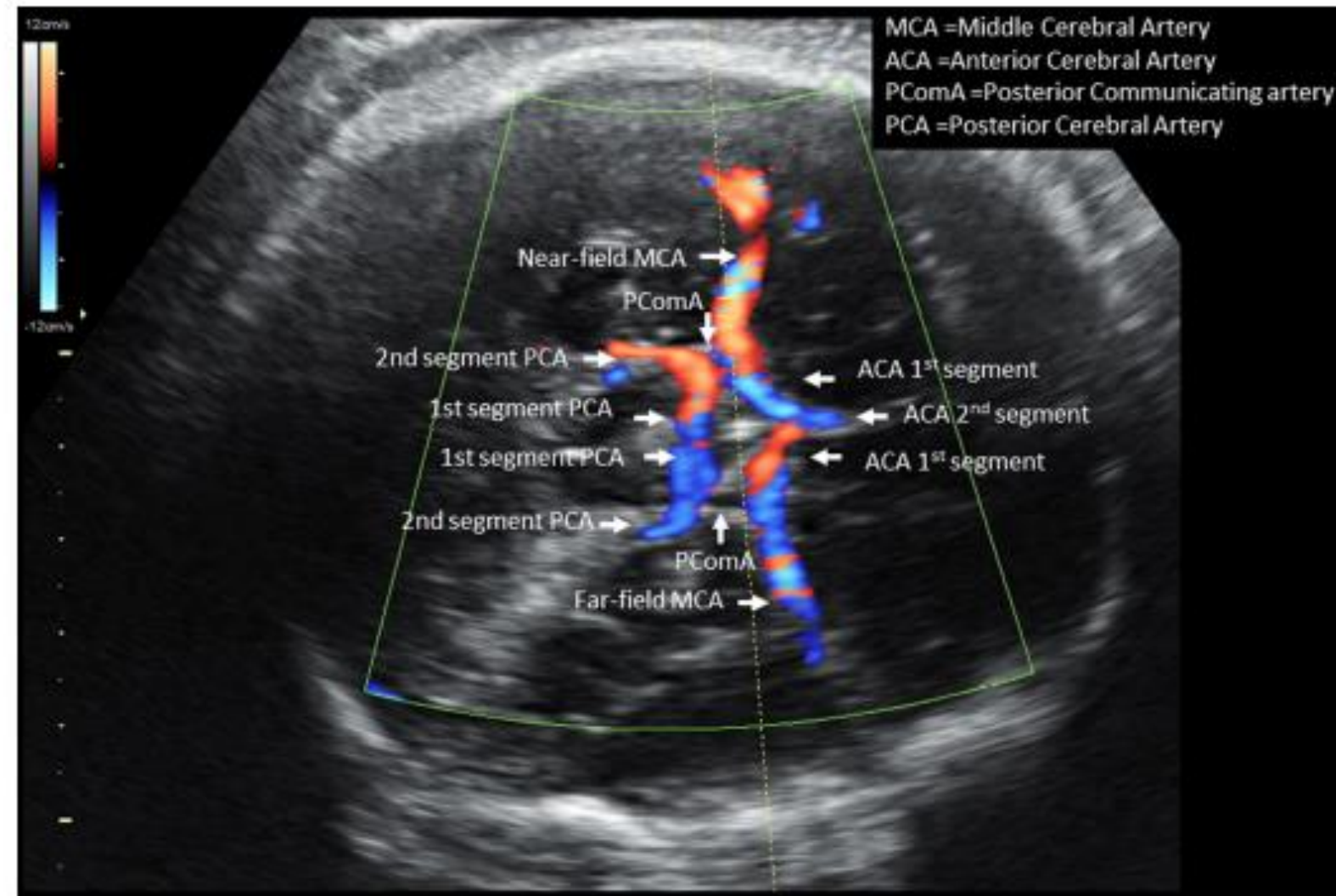


Figure 5 Color flow mapping of the circle of Willis.

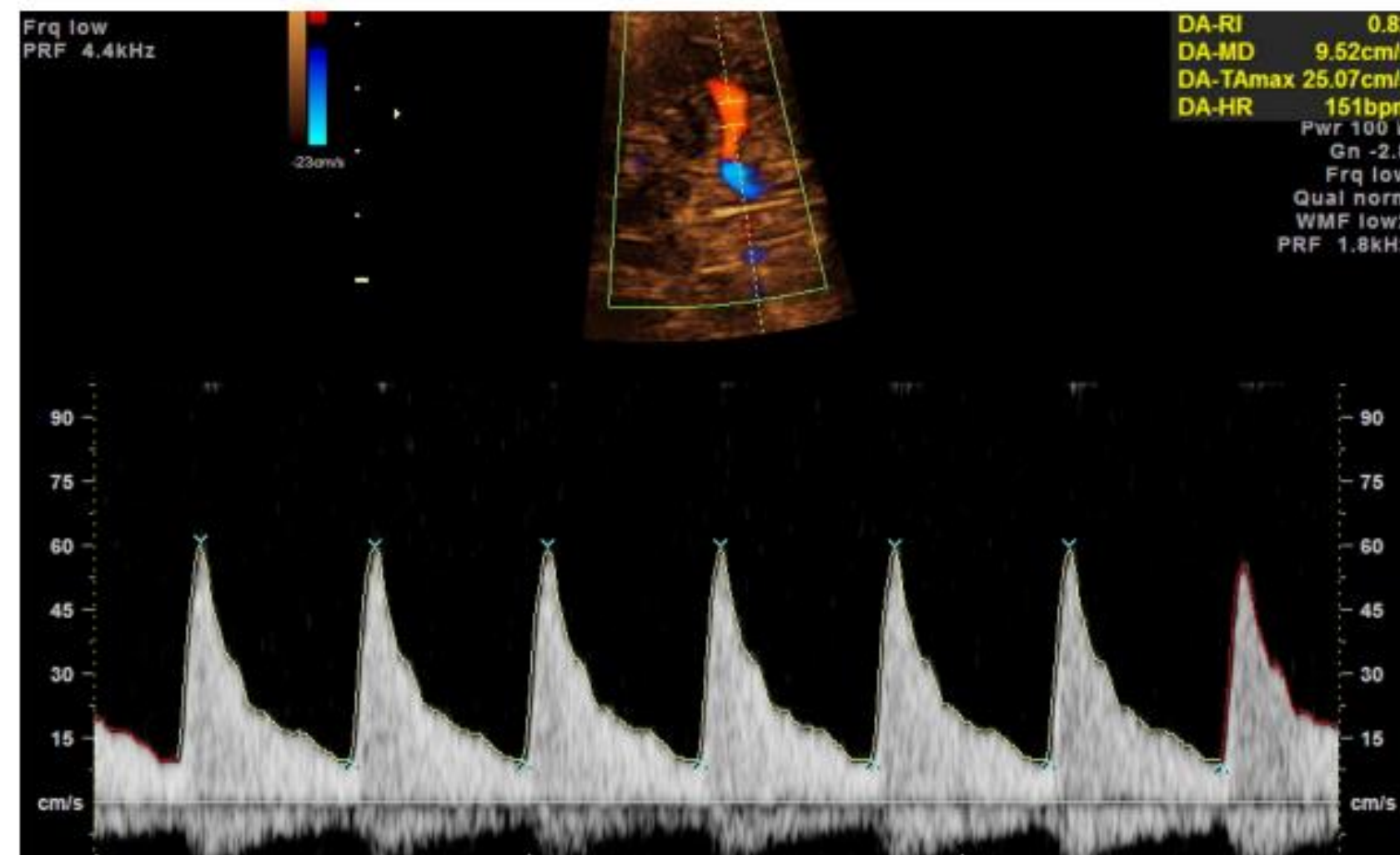


Figure 6 Acceptable Doppler waveform from the middle cerebral artery. Note the angle of insonation has been adjusted to be nearly 0° .

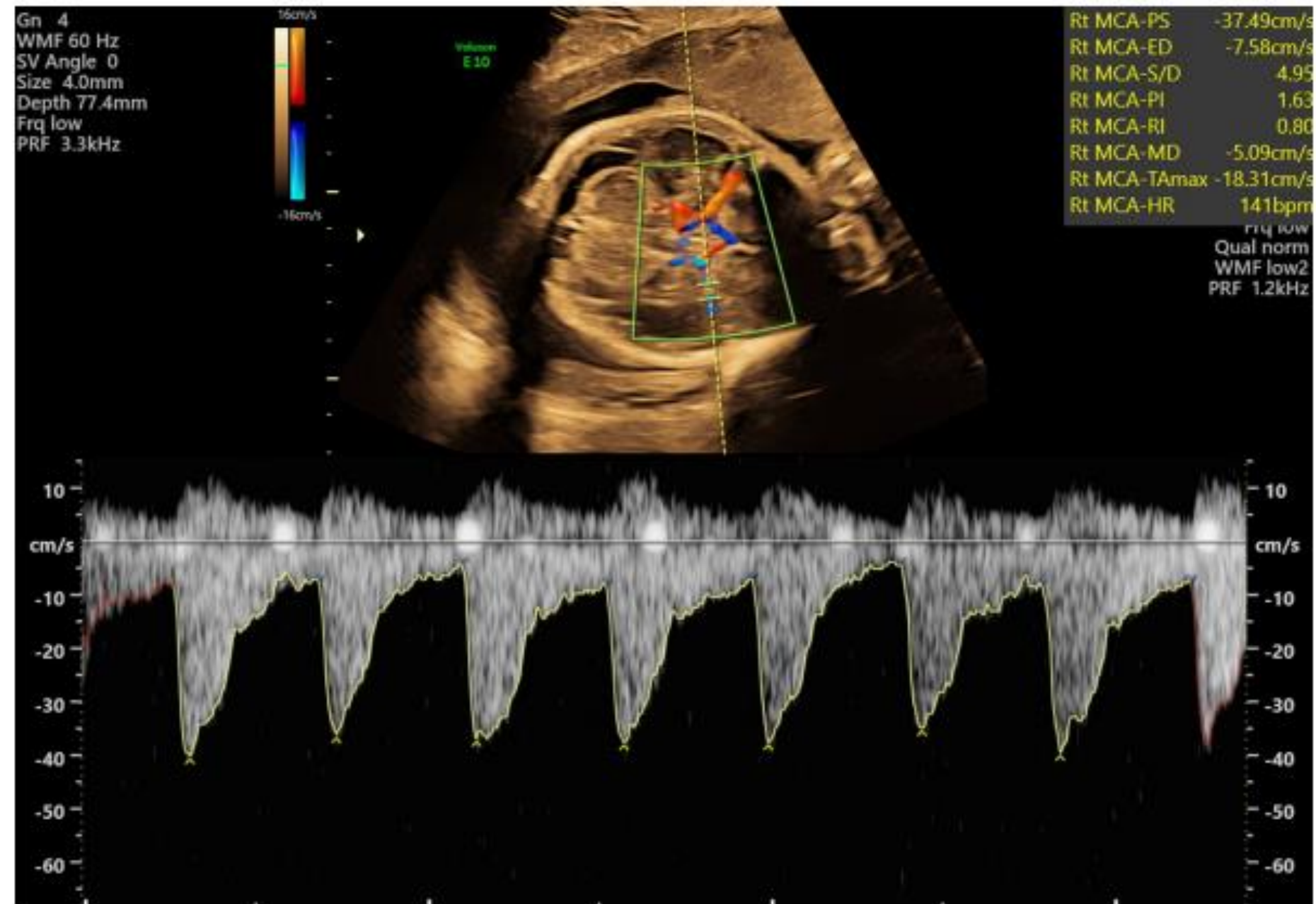


Figure 7 Middle cerebral artery (MCA) Doppler waveforms obtained from the far-field MCA. Note the 0° angle of insonation.

Cerebroplacental ratio and the umbilicocerebral ratio

The physiological basis for clinical application of the cerebroplacental Doppler ratio (CPR) is two-fold. The CPR is a reflection of the arterial redistribution that occurs during preferential brain perfusion in response to fetal hypoxemia ('brain sparing'). It amplifies mathematically the effect of abnormal hemodynamics in the umbilical and cerebral circulations and correlates more closely with the fetal partial pressure of oxygen (pO₂) than does either of its component indices.

- The ratio of Doppler indices from the cerebral and umbilical arterial circulations has been calculated variously, using indices of the MCA, anterior cerebral artery, vertebral artery or internal carotid artery, using umbilical artery indices in the denominator rather than the numerator, and using PI or RI, for semiquantitative analysis of waveforms.

- **The greatest body of scientific evidence has been accumulated for the simple ratio of the MCA-PI divided by the umbilical artery PI (i.e. the CPR), and the second most commonly utilized ratio is its inverse, i.e. the umbilical artery PI divided by the MCA-PI (umbilicocerebral ratio (UCR)).**
- The CPR or UCR should be interpreted using gestational-age-related reference ranges rather than a single cut-off.

Technique for obtaining ductus venosus Doppler waveforms

- The ductus venosus (DV) connects the intra-abdominal portion of the umbilical vein to the left portion of the inferior vena cava, just below the diaphragm. The vessel is identified by visualizing this connection by 2D imaging, either in a mid-sagittal longitudinal plane of the fetal trunk or in an oblique transverse plane through the upper abdomen.
- Color flow mapping demonstrating the high velocity at the narrow entrance of the DV confirms its identification and indicates the standard sampling site for Doppler measurements.
- Doppler measurement is best achieved in the sagittal plane from the anterior lower fetal abdomen, since alignment with the ductal isthmus can be well controlled.
- Sagittal insonation through the chest is also a good option, but more demanding. An oblique section provides reasonable access for an anterior or posterior insonation, yielding robust waveforms but with less control of angle and absolute velocities.
- In early pregnancy and in compromised pregnancies, particular care should be taken to reduce the sample volume appropriately, in order to ensure clean recording of the lowest velocity during atrial contraction.
 - The waveform is usually triphasic, but biphasic and non-pulsating recordings, though rarer, may be seen in healthy fetuses.

The velocities are relatively high, between 55 and 90 cm/s, for most of the second half of pregnancy³⁰, but are lower in early pregnancy.

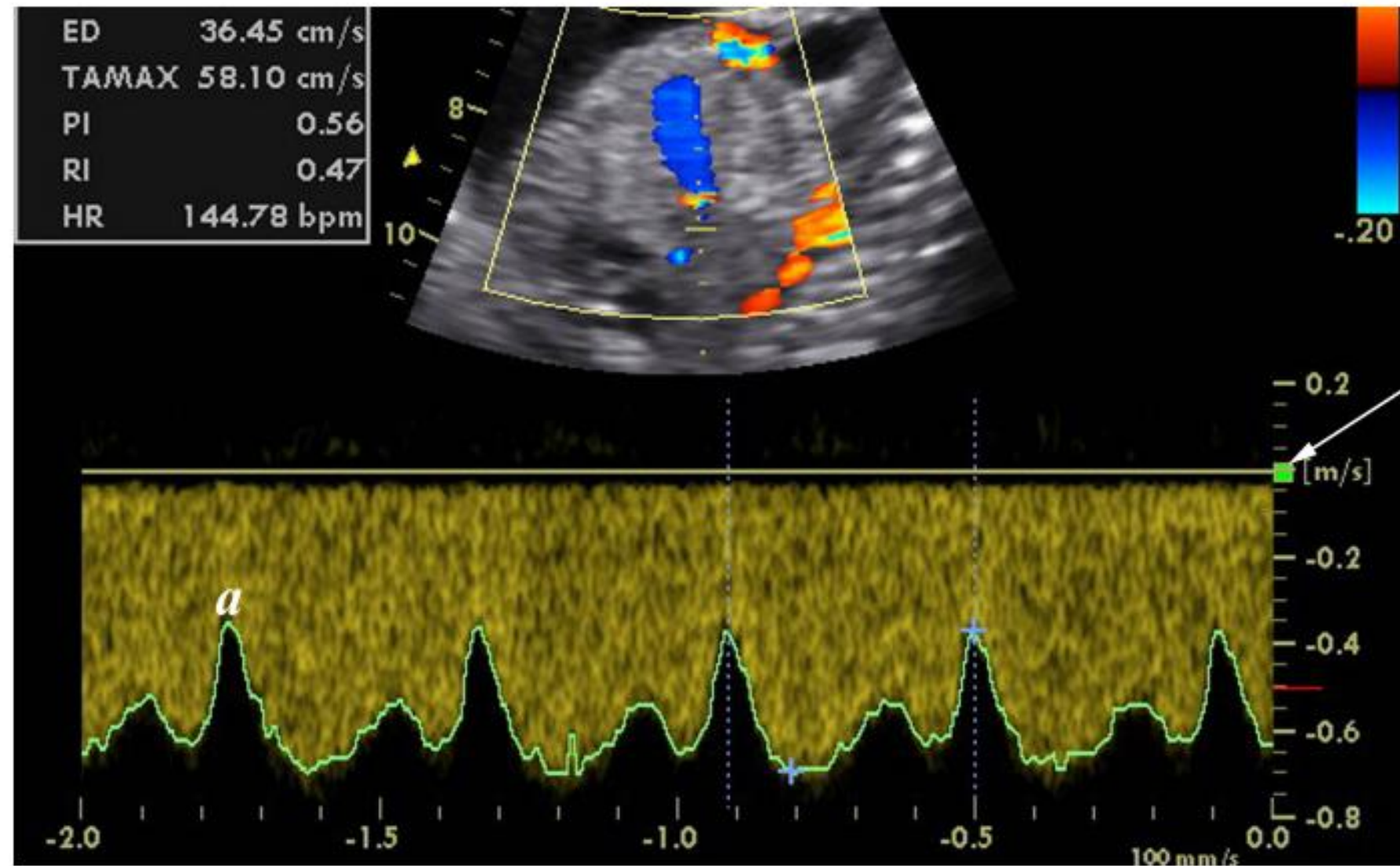


Figure 8 Ductus venosus Doppler recording with sagittal insonation aligning with the isthmic portion, without angle correction. The low-velocity vessel wall filter (arrow) does not interfere with the a-wave (*a*), which is far from the zero line. A high sweep speed allows detailed visualization of variation in velocity.

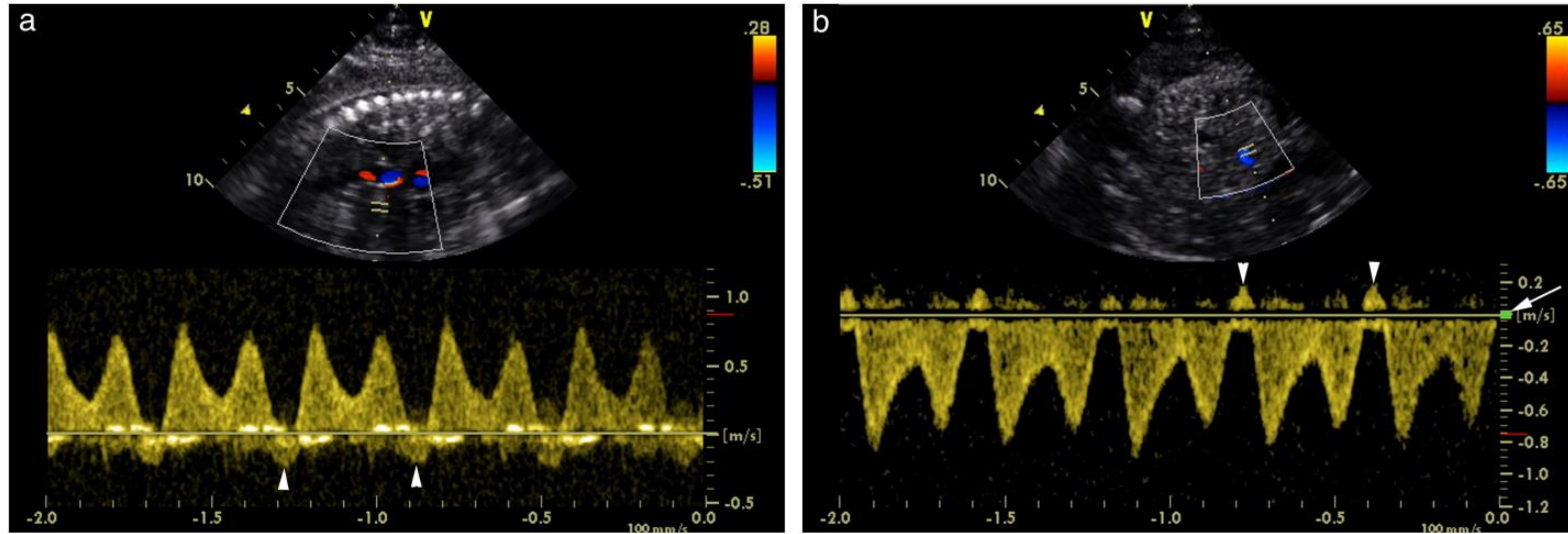


Figure 9 (a) Ductus venosus recording showing increased pulsatility at 36 weeks. Interference, including highly echogenic clutter along the zero line, makes it difficult to verify the reversed component during atrial contraction (arrowheads). (b) A repeat recording with slightly increased low-velocity vessel wall filter (arrow) improves quality and allows clear visualization of the reversed velocity component during atrial contraction (arrowheads).

Which indices should be used?

S/D ratio, RI and PI are the three best known indices to describe arterial flow velocity waveforms. All three are highly correlated. RI and S/D ratio estimate the relationship between PSV and EDV in the Doppler waveform ($RI = (S - D)/S$, $S/D \text{ ratio} = S/D$, where S is peak systolic velocity and D is end-diastolic velocity). PI takes into account the PSV, the EDV and the time-averaged mean of the maximum frequency shift over the cardiac cycle ($PI = (S - D)/TAMX$, where S is peak systolic velocity, D is end-diastolic velocity and TAMX is the maximum velocity recorded in the MVE averaged over the cardiac cycle; TAMX should not be confused with time-averaged intensity-weighted mean velocity (TAV or Vm)). In Doppler waveforms showing dynamic changes in the systolic or diastolic components (i.e. in case of uterine artery waveform with presence of notching, or reversed EDV in umbilical artery waveform), **PI gives a better estimate of the characteristics of the waveform than do RI or S/D ratio**. PI shows a linear correlation with vascular resistance, as opposed to both S/D ratio and RI, which show a parabolic relationship with increasing vascular resistance.

. **Additionally, PI does not approach infinity when there are absent or reversed diastolic values. PI is the index recommended for use in clinical practice and research.**

Two indices are described for pulsed-wave Doppler analysis of the veins(**DV**).

The most commonly used is the **pulsatility index for veins (PIV)**.

This is calculated as $PIV = (V_s - V_a)/TAMX$, where V_s is the peak forward velocity during ventricular systole and V_a is the lowest forward velocity or peak reversed velocity during atrial contraction (the 'a-wave').

The peak velocity index for veins (PVIV) is reported less frequently and is not featured on most auto-measure packages. PVIV is calculated as $(V_s - V_a)/V_d$, where V_d is the peak forward velocity during atrial contraction (diastole).

The use of PIV is recommended in clinical practice.

Table 1 Pulsatility index in the umbilical and middle cerebral arteries and cerebroplacental Doppler ratio in 306 normal fetuses

<i>Gestational week</i>	N	<i>Umbilical artery</i>		<i>Middle cerebral artery</i>		<i>CPR</i>	
		<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>
20	25	1.31	0.26	1.76	0.24	1.37	0.40
21	15	1.27	0.18	1.79	0.20	1.44	0.25
22	9	1.28	0.17	1.87	0.33	1.48	0.29
23	11	1.12	0.12	1.65	0.16	1.49	0.23
24	21	1.21	0.14	1.85	0.21	1.53	0.22
25	13	1.13	0.16	2.03	0.41	1.83	0.48
26	14	1.11	0.13	2.09	0.43	1.92	0.55
27	17	1.07	0.17	2.18	0.68	2.12	0.61
28	17	1.05	0.13	2.21	0.41	2.13	0.52
29	17	1.11	0.19	2.02	0.31	1.86	0.43
30	12	1.04	0.23	2.34	0.33	2.34	0.55
31	19	0.99	0.13	2.21	0.31	2.29	0.34
32	10	0.93	0.19	1.81	0.19	2.03	0.48
33	17	0.92	0.17	1.90	0.38	2.10	0.40
34	21	0.89	0.13	1.79	0.27	2.10	0.45
35	13	0.91	0.11	1.81	0.31	2.01	0.34
36	19	0.93	0.18	1.80	0.27	2.01	0.46
37	6	0.95	0.24	2.06	0.68	2.25	0.66
38	11	0.89	0.16	1.66	0.30	1.90	0.41
39	8	1.01	0.17	1.64	0.26	1.64	0.29
40	11	0.75	0.16	1.29	0.21	1.80	0.44

5th percentile=
Mean –(1.65 * SD)

CPR, cerebroplacental Doppler ratio; SD, standard deviation.

Table 2 Reference intervals for mean uterine artery pulsatility index

GA (weeks)	5 th centile	50 th centile	95 th centile
11	1.18	1.79	2.70
12	1.11	1.68	2.53
13	1.05	1.58	2.38
14	0.99	1.49	2.24
15	0.94	1.41	2.11
16	0.89	1.33	1.99
17	0.85	1.27	1.88
18	0.81	1.20	1.79
19	0.78	1.15	1.70
20	0.74	1.10	1.61
21	0.71	1.05	1.54
22	0.69	1.00	1.47
23	0.66	0.96	1.41
24	0.64	0.93	1.35
25	0.62	0.89	1.30
26	0.60	0.86	1.25
27	0.58	0.84	1.21
28	0.56	0.81	1.17
29	0.55	0.79	1.13
30	0.54	0.77	1.10
31	0.52	0.75	1.06
32	0.51	0.73	1.04
33	0.50	0.71	1.01
34	0.50	0.70	0.99
35	0.49	0.69	0.97
36	0.48	0.68	0.95
37	0.48	0.67	0.94
38	0.47	0.66	0.92
39	0.47	0.65	0.91
40	0.47	0.65	0.90
41	0.47	0.65	0.89

Transvaginal and transabdominal ultrasound examinations were performed on pregnancies at 11–14 weeks and 15–41 weeks, respectively. GA, gestational age.

DISCUSSION

This study describes new GA-based reference ranges of mean UtA-PI between 11 and 41 weeks of gestation in an

TABLE A-14 Percentile Values for Fetal Abdominal Circumference					
Menstrual Age (Wks)	ABDOMINAL CIRCUMFERENCE (CM) BY PERCENTILE				
	3rd	10th	50th	90th	97th
14	6.4	6.7	7.3	7.9	8.3
15	7.5	7.9	8.6	9.3	9.7
16	8.6	9.1	9.9	10.7	11.2
17	9.7	10.3	11.2	12.1	12.7
18	10.9	11.5	12.5	13.5	14.1
19	11.9	12.6	13.7	14.8	15.5
20	13.1	13.8	15.0	16.3	17.0
21	14.1	14.9	16.2	17.6	18.3
22	15.1	16.0	17.4	18.8	19.7
23	16.1	17.0	18.5	20.0	20.9
24	17.1	18.1	19.7	21.3	22.3
25	18.1	19.1	20.8	22.5	23.5
26	19.1	20.1	21.9	23.7	24.8
27	20.0	21.1	23.0	24.9	26.0
28	20.9	22.0	24.0	26.0	27.1
29	21.8	23.0	25.1	27.2	28.4
30	22.7	23.9	26.1	28.3	29.5
31	23.6	24.9	27.1	29.4	30.6
32	24.5	25.8	28.1	30.4	31.8
33	25.3	26.7	29.1	31.5	32.9
34	26.1	27.5	30.0	32.5	33.9
35	26.9	28.3	30.9	33.5	34.9
36	27.7	29.2	31.8	34.4	35.9
37	28.5	30.0	32.7	35.4	37.0
38	29.2	30.8	33.6	36.4	38.0
39	29.9	31.6	34.4	37.3	38.9
40	30.7	32.4	35.3	38.2	39.9

Adapted from Hadlock FP, Deter RL, Harrist RB, et al: Estimating fetal age: computer-assisted analysis of multiple fetal growth parameters. Radiology 152:497, 1984.

		Weight percentiles† for the local population										
		99th	97th	95th	90th	75th	Mean	25th	10th	5th	3rd	1st
Gestational age* (weeks)	24	820	786	768	741	695	644	593	547	520	502	468
	25	957	918	897	865	812	752	692	639	607	586	547
	26	1110	1064	1040	1003	941	872	803	741	703	679	634
	27	1278	1225	1198	1155	1083	1004	924	853	810	782	730
	28	1461	1401	1369	1320	1238	1147	1057	975	926	894	834
	29	1658	1590	1554	1498	1405	1302	1199	1106	1051	1015	947
	30	1869	1792	1751	1689	1584	1468	1352	1247	1184	1144	1067
	31	2091	2005	1960	1890	1773	1643	1513	1395	1325	1280	1194
	32	2324	2228	2178	2100	1970	1825	1681	1551	1473	1422	1327
	33	2564	2459	2403	2317	2173	2014	1854	1711	1625	1569	1464
	34	2809	2694	2632	2538	2381	2206	2032	1874	1780	1719	1604
	35	3056	2930	2864	2761	2590	2400	2210	2039	1937	1870	1745
	36	3301	3165	3093	2983	2798	2593	2387	2203	2092	2020	1885
	37	3540	3395	3318	3199	3001	2781	2561	2362	2244	2167	2021
	38	3770	3615	3533	3407	3196	2961	2727	2516	2390	2308	2153
	39	3987	3823	3736	3603	3380	3132	2884	2660	2527	2440	2276
	40	4186	4014	3923	3783	3549	3288	3028	2794	2653	2562	2390
	41	4365	4185	4090	3944	3700	3428	3157	2913	2766	2671	2492

From Acharya G, Vileigand T, Densten GK, et al. Reference ranges for serial measurements of umbilical artery Doppler indices in the second half of pregnancy. Am J Obstet Gynecol 192:937, 2005.

TABLE D-4 Resistance Index of the Umbilical Artery Between 20 and 40 Weeks of Gestation

Gestation (wk)	5th Percentile	50th Percentile	95th Percentile
20	0.567	0.690	0.802
21	0.557	0.680	0.793
22	0.548	0.671	0.784
23	0.539	0.663	0.776
24	0.530	0.655	0.768
25	0.522	0.646	0.760
26	0.514	0.639	0.752
27	0.506	0.631	0.745
28	0.498	0.623	0.737
29	0.490	0.615	0.730
30	0.482	0.608	0.723
31	0.474	0.600	0.715
32	0.465	0.592	0.707
33	0.457	0.584	0.700
34	0.449	0.576	0.692
35	0.440	0.567	0.684
36	0.431	0.559	0.675
37	0.422	0.550	0.667
38	0.412	0.540	0.657
39	0.402	0.530	0.648
40	0.390	0.519	0.637

From Merz E (ed): Ultrasonography in Obstetrics and Gynecology. Stuttgart, Thieme, 2005, pp 469-480, 613, 614.

TABLE D-5 Pulsatility Index of the Umbilical Artery Between 20 and 40 Weeks of Gestation

Gestation (wk)	5th Percentile	50th Percentile	95th Percentile
20	0.940	1.216	1.505
21	0.913	1.189	1.476
22	0.890	1.165	1.450
23	0.869	1.142	1.427
24	0.849	1.122	1.405
25	0.831	1.102	1.385
26	0.813	1.084	1.365
27	0.798	1.065	1.346
28	0.780	1.048	1.327
29	0.764	1.031	1.308
30	0.748	1.014	1.290
31	0.732	0.997	1.272
32	0.716	0.980	1.254
33	0.700	0.963	1.236
34	0.684	0.946	1.218
35	0.668	0.928	1.199
36	0.651	0.910	1.180
37	0.634	0.891	1.160
38	0.615	0.872	1.139
39	0.595	0.851	1.117
40	0.573	0.828	1.093

From Merz E (ed): Ultrasonography in Obstetrics and Gynecology. Stuttgart, Thieme, 2005, pp 469-480, 613, 614.

