Acute Maternal Hyperoxygenation

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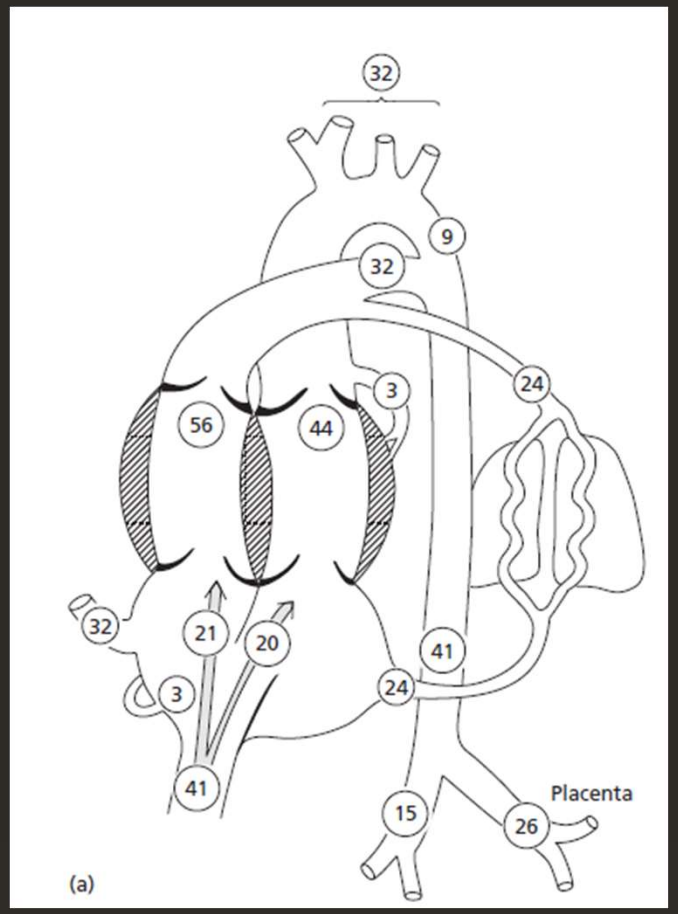
Objectives

- What is acute maternal hyperoxygenation (MH) testing
- Acute MH testing protocol
- Indications
- Interpretation
- Congenital Heart disease specific changes
- Clinical usage in our fetal echocardiography lab
- Case examples showing clinical use

Introduction

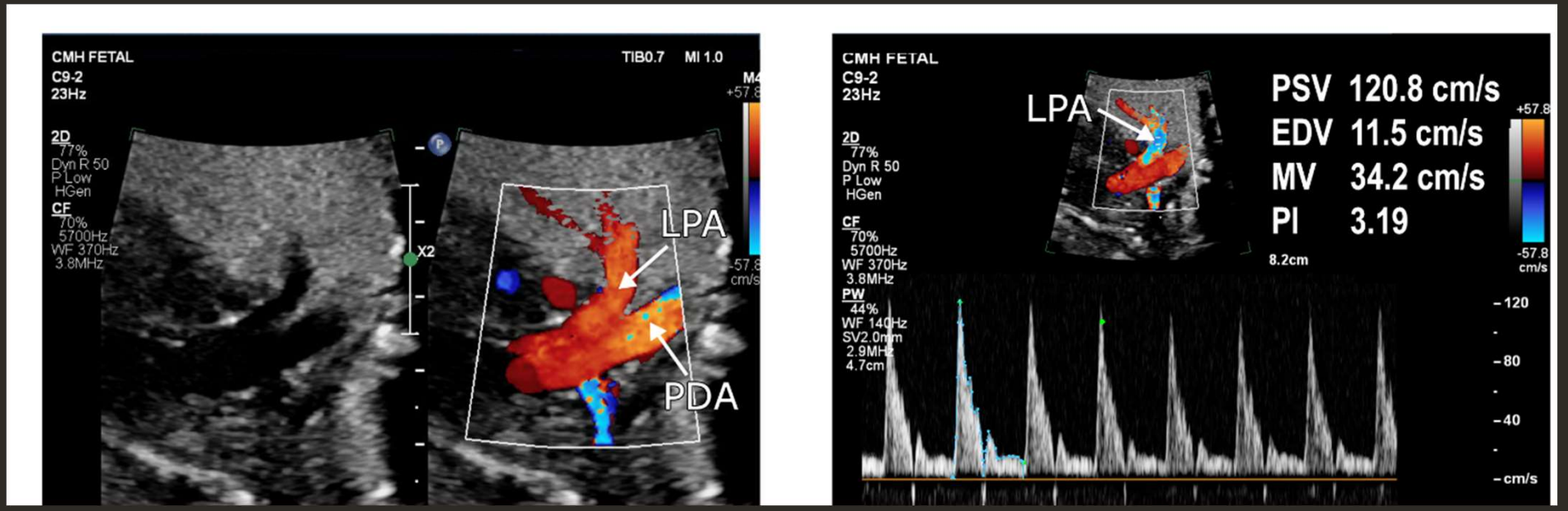
- Normal fetal circulation
- Percentages of flow through the main vascular channels for the late-gestation human fetus

Rudolph AM. Congenital diseases of the Heart. Wiley-Blackwell, 2009.



Introduction continued

- Acute MH testing leverages two aspects of fetal cardiovascular physiology:
  (1) the normally high fetal PVR
  (2) change in PVR upon exposure to increased fetal oxygen tension
- Acute MH exposure to the fetus results in PVR reduction
- This response has been demonstrated as early as 26 weeks
- Response tends to become more prevalent in the third trimester



How do we assess pulmonary vasoreactivity

- Assess branch PA pulsatility index (PI)
- Assess increase in pulmonary venous flow
- A 10-20% drop in PI is generally considered “reactive”

Is assessing pulmonary vasoreactivity helpful?

- The presence or absence of fetal pulmonary vascular reactivity is quite useful information
- Lack of reactivity in certain cardiac and non-cardiac defects, may signal poor postnatal outcomes and indicate the need for urgent postnatal resuscitation

What do reactive fetuses show

- Reactive fetuses experience changes similar to postnatal circulatory shifts including:
  - Increased pulmonary blood flow
  - Increased left-sided filling
  - Changes in foramen ovale geometry
- This simulation might predict unfavorable changes that may occur postnatally such as profound hypoxemia due to:
  - Persistent pulmonary hypertension
  - Restrictive atrial septum in HLHS or dTGA
  - Increased venous obstruction in TAPVC

Acute MH Timing and O2 delivery

- > 34 weeks gestational age
- Fetal Echo to be obtained in 2 states:
  - At rest (Baseline) – with pregnant woman breathing room air
  - Acute Maternal hyperoxygenation (MH) – Administer 100% FiO2 via a non-rebreather mask at 8L/min flow to the pregnant woman for 10 minutes.
  - *Optional recovery phase*

Indications

- Useful (some supporting scientific literature exists):
  - HLHS and variants with concern for restrictive or intact atrial septum
  - d-TGA with intact ventricular septum or small VSD
  - Aneurysmal atrial septum bowing into the left atrium with a qualitatively borderline left ventricle
  - Non-cardiac abnormalities e.g., pulmonary hypoplasia, congenital diaphragmatic hernia
- May be useful (scant or no scientific literature exists):
  - Suspected obstructed TAPVC
  - Ebstein's anomaly/Tricuspid valve dysplasia (TVD) with no antegrade pulmonary blood flow and no pulmonary insufficiency

Fetal Echo Parameters to assess at baseline and with acute MH

Site/Structure	Specifics
Right/Left Branch PA	PWD in mid PA with interrogation angle <15° to calculate PI
One right and one left pulmonary vein PWD	S velocity, FVTI, RVTI, F/R VTI
Atrial septum	Motion by 2D, presence/direction of color flow
Ductus arteriosus	Presence/direction of color flow, PWD
4-chamber view	Assessment of systolic ventricular function
4-chamber color	Assess tricuspid/mitral valve for new/worsening regurgitation
Middle cerebral artery	PWD to obtain PI

Additional fetal Echo Parameters specific to CHD

Aneurysmal atrial septum bowing into the left atrium with a qualitatively borderline left ventricle	
	Direction of color flow/PWD in the transverse arch and aortic isthmus
Total anomalous pulmonary venous connection	
	Vertical vein PWD. Measure peak velocity, mean gradient, and description of Doppler waveform (monophasic, biphasic or triphasic)
Ebstein's anomaly/Tricuspid valve dysplasia with no pulmonary insufficiency	
	Pulmonary valve 2D, color and PWD to assess for pulmonary valve antegrade flow and valve regurgitation
	Right ventricular cardiac output

Interpretation

- Pulmonary vascular reactivity:
  - Decrease in branch PA PI >10%*
  - Increase in pulmonary vein peak S velocity, velocity time integral (VTI), and forward to reverse velocity time integral (F/R VTI) if flow reversal present*

* No definitively established cutoff values

CHD specific changes

- HLHS with restrictive or intact atrial septum
  - Assess pulmonary vascular reactivity
  - Change in pulmonary vein F/R VTI to assess likelihood of need for atrial septoplasty

- Borderline left ventricle associated with aneurysmal septum primum
  - Change in flow direction in the transverse arch and aortic isthmus to assess responsiveness of left ventricle to increase in preload

CHD specific changes

- d-TGA
  - Assess pulmonary vascular reactivity (as above) along with flow direction in the ductus arteriosus to assess likelihood of pulmonary hypertension at delivery
  - Foramen ovale size and change in flow pattern to assess likelihood of need for balloon atrial septostomy

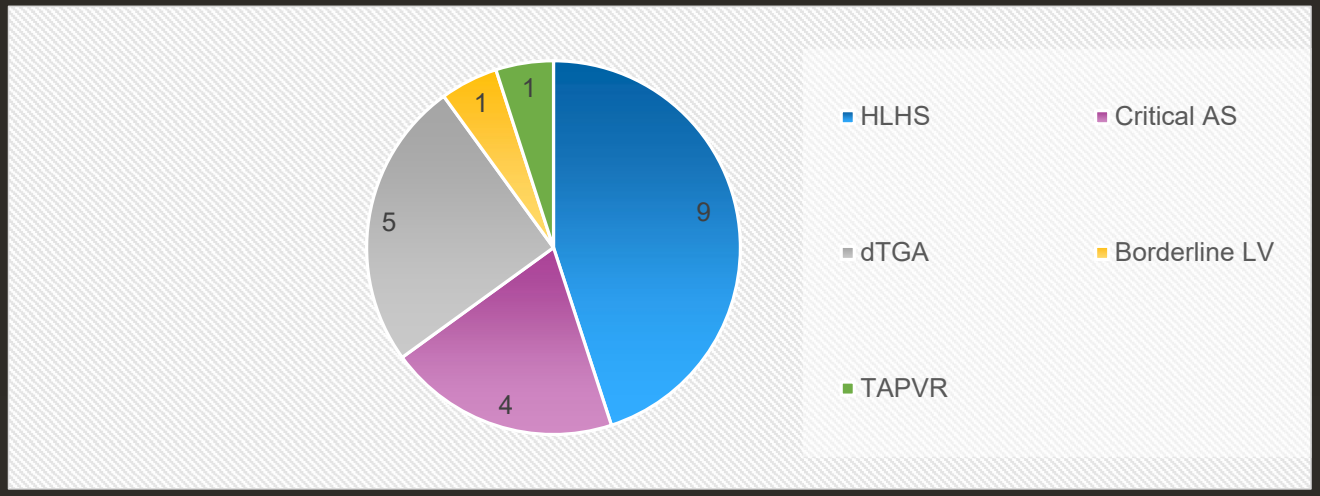
CHD specific changes

- TAPVC with suspected obstruction
  - Assess pulmonary vascular reactivity (see above)
  - Change in vertical vein peak velocity, mean gradient, and waveform to assess likelihood of obstruction

- Ebstein's anomaly/TVD with no antegrade pulmonary flow (and no pulmonary insufficiency)
  - Assess pulmonary vascular reactivity (see above)
  - Assess for antegrade flow across pulmonary valve to help differentiate functional from true anatomic pulmonary atresia

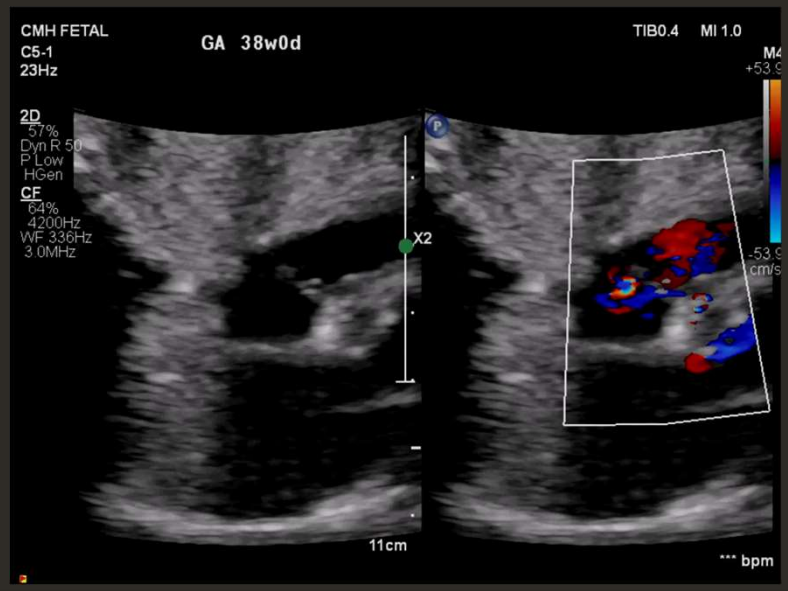
Clinical usage in our lab

- Acute MH usage in our lab in a protocolized manner since Jan 2022
- Jan 2022-May 2024: 20 patients



Clinical Case Example 1

- 35-year-old G3P2 female being followed for prenatal diagnosis of Turner syndrome and HLHS



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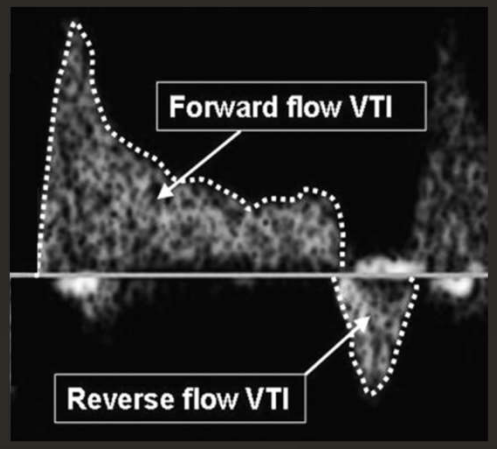
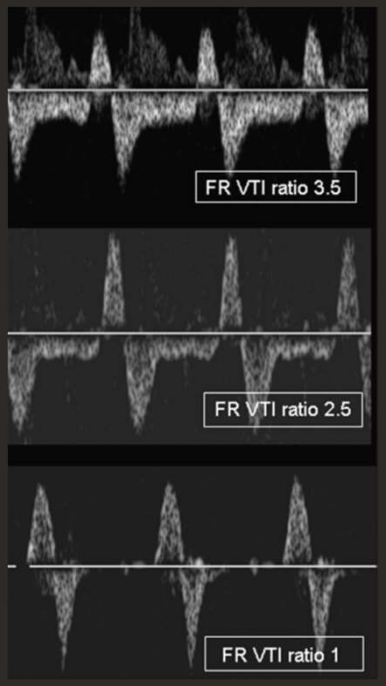
How to assess need for emergent septoplasty

Prediction and perinatal management of severely restrictive atrial septum in fetuses with critical left heart obstruction: Clinical experience using pulmonary venous Doppler analysis

Allison Divanović, MD, Kan Hor, MD, James Cnota, MD, Russel Hirsch, MD,
Meredith Kinsel-Ziter, RDCS, and Erik Michelfelder, MD





What can acute MH add

Vasoreactive Response to Maternal Hyperoxygenation in the Fetus With Hypoplastic Left Heart Syndrome

Anita Szwast, MD; Zhiyun Tian, MD; Margaret McCann, RDMS;
Denise Donaghue, RN, MSN; Jack Rychik, MD

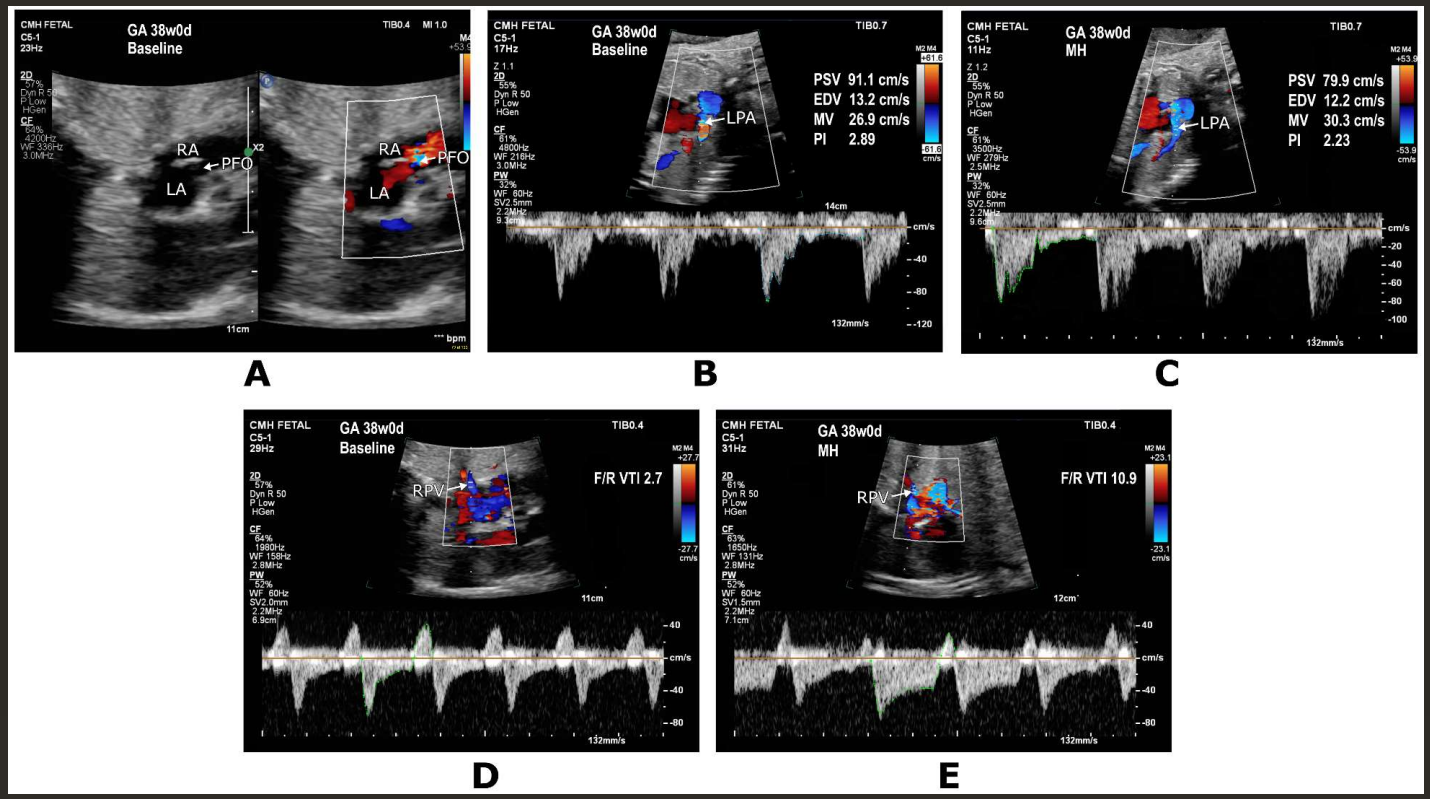
on the atrial septum at birth. Using a cutoff value of <10% vasoreactivity, the sensitivity of MH testing for determining need for immediate intervention at birth is 100% (0.46 to 1.0); specificity, 94% (0.78 to 0.99); positive predictive value,

Maternal Hyperoxygenation Testing in Fetuses with Hypoplastic Left-Heart Syndrome: Association with Postnatal Atrial Septal Restriction

Christopher Mardy[a] Michelle Kaplinski[a, b] Lynn Peng[a] Yair J. Blumenfeld[b, c]
David M. Kwiatkowski[a] Theresa A. Tacy[a, b] Shiraz A. Maskatia[a, b]

Fetuses with "intermediate" Pvein prograde:retrograde VTI ratios at baseline (between 3 and 7) are likely to benefit most from MHO testing.

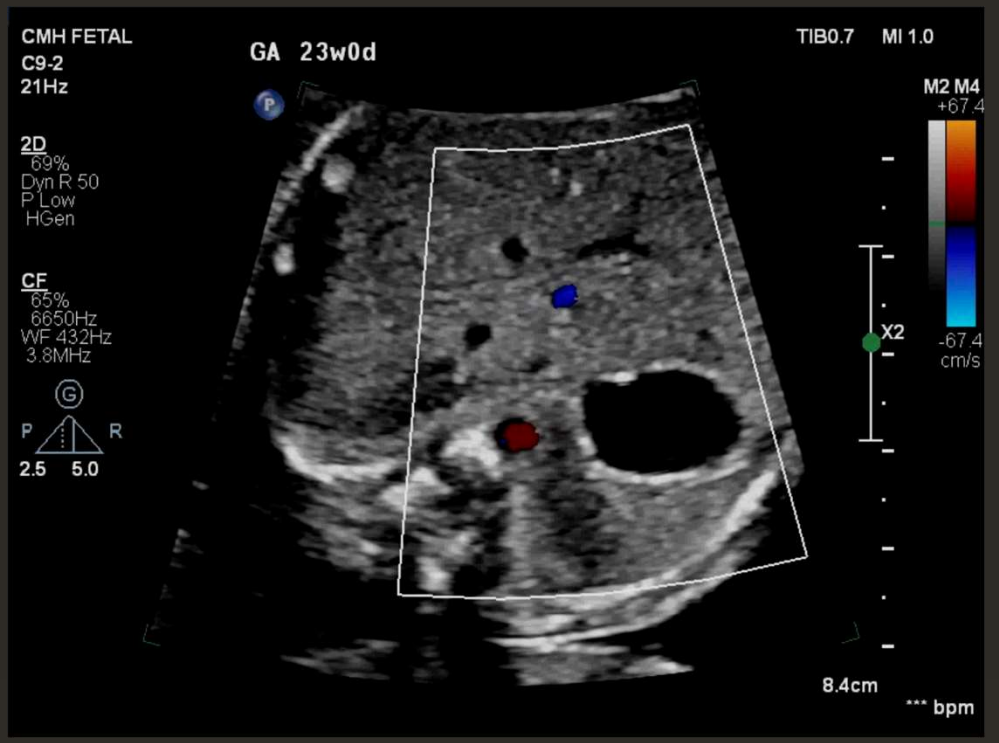
Case example 1 with acute MH



Postnatal course

- Delivery classification: Class III (possible hemodynamic instability)
- Induction at term
- Vaginal delivery
- Apgar scores 8 and 9
- Initial echocardiogram showed small 3mm PFO
- Sats remained stable in the 80s for 12 days
- Patient underwent hybrid palliation with PA bands on DOL 11 and PDA stent/BAS on DOL 12

Clinical Case Example 2



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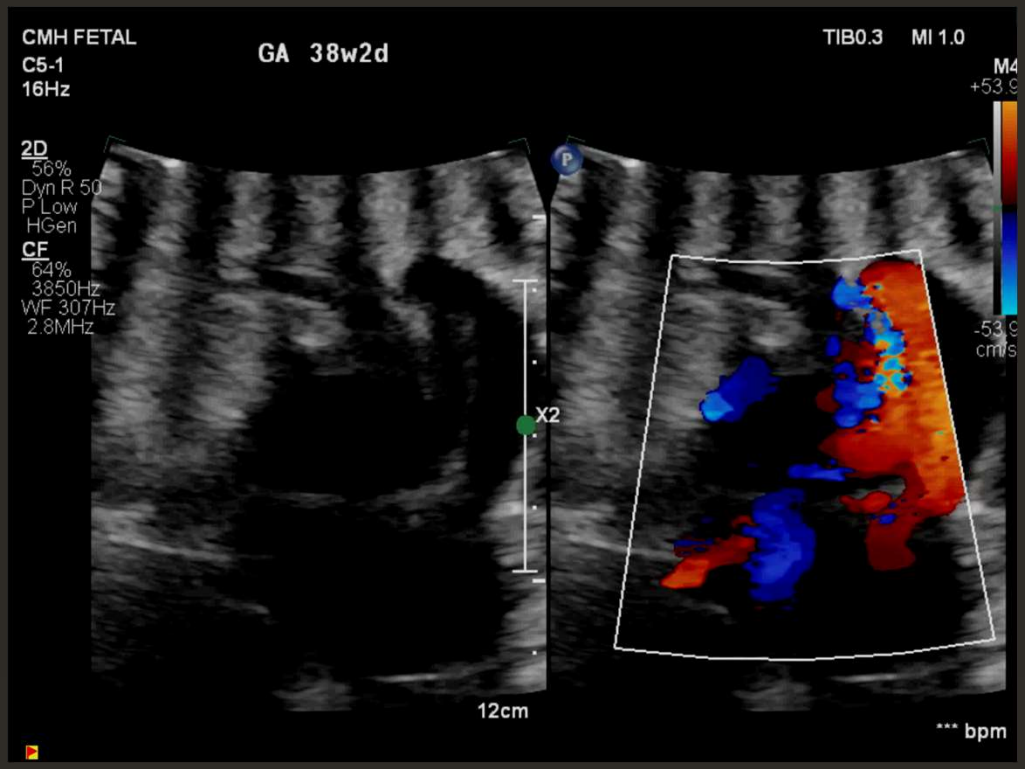
TGA/IVS Late gestation atrial septum



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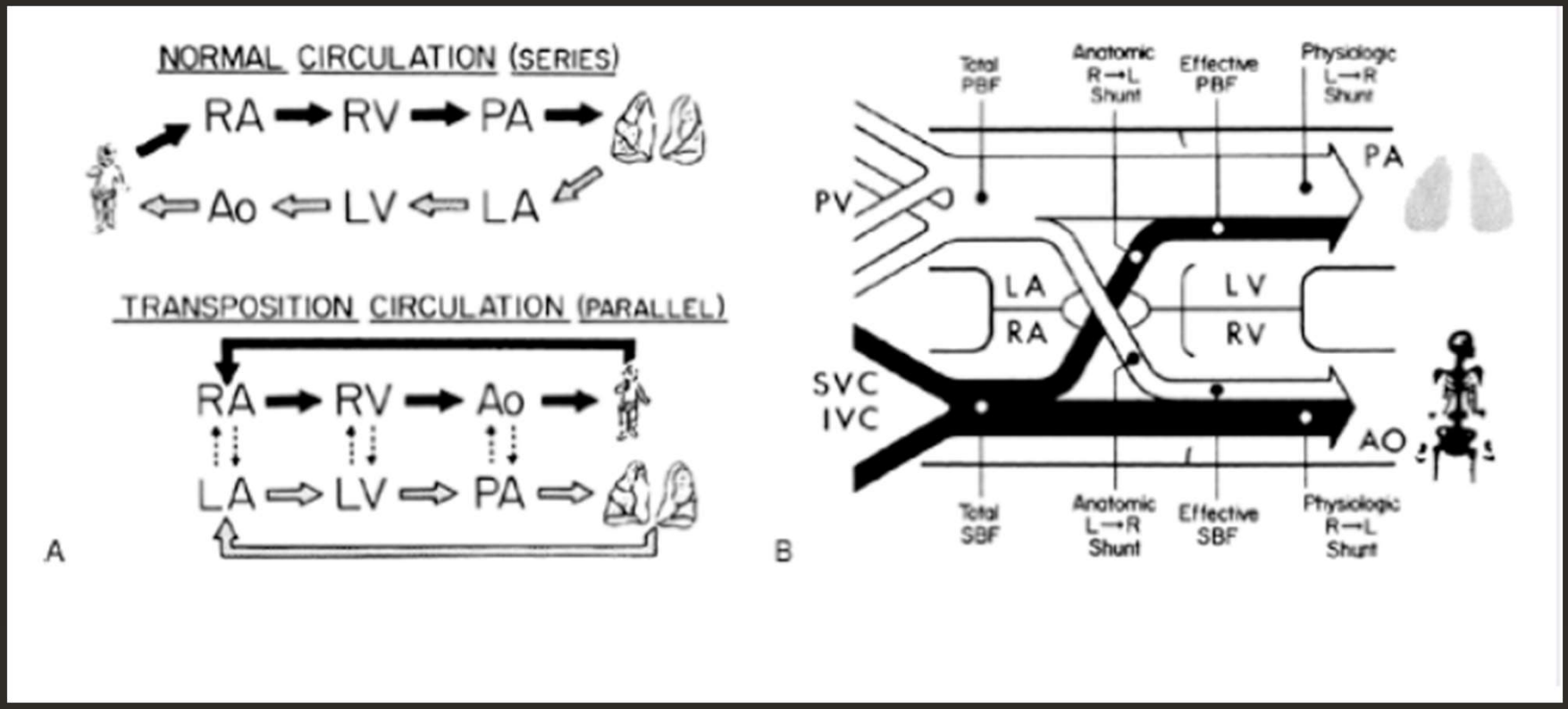
Postnatal circulation in TGA



Predicting hypoxia at birth and need for emergent BAS

- Multiple studies have tried to assess this.
- Published prenatal markers predicting need for BAS in fetal d-TGA include:
  - Fixed, flat, or hypermobile atrial septum
  - Absolute PFO size <7mm
  - PFO to total septal length ratio < 0.510
  - Restrictive ductus arteriosus
  - Reversed diastolic flow in the ductus
  - Higher maximal velocity of flow within the pulmonary veins

But are we good enough in predicting BAS?

THE JOURNAL OF MATERNAL-FETAL & NEONATAL MEDICINE
2022, VOL. 35, NO. 3, 598–606
https://doi.org/10.1080/14767058.2020.1725883

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REVIEW ARTICLE

Check for updates

Prenatal risk factors for urgent atrial septostomy at birth in fetuses with transposition of the great arteries: a systematic review and meta-analysis

0.51 ± 0.14, $p = .001$) were significantly smaller in fetuses requiring compared to those not undergoing urgent BAS at birth. The diagnostic accuracy of each independent ultrasound marker of the need for urgent BAS showed an overall good specificity but a low sensitivity.

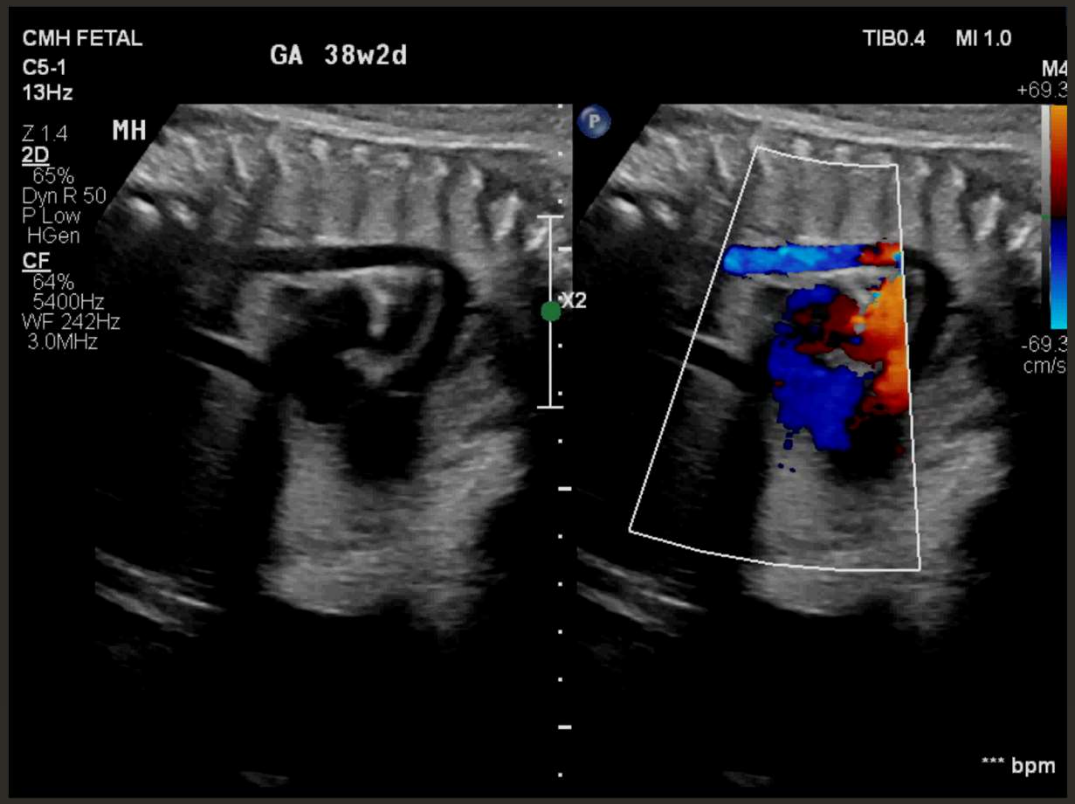
Pediatric Cardiology (2021) 42:1575–1584
https://doi.org/10.1007/s00246-021-02642-w

ORIGINAL ARTICLE

Reliability of Fetal Echocardiography in Predicting Postnatal Critical Hypoxia in Patients with Transposition of Great Arteries and Intact Ventricular Septum

control group compared to patients with D-TGAIVS. Fetal echocardiographic aspects cannot predict patients with D-TGAIVS who will not need Urgent balloon atrial septostomy. Therefore, we recommended a delivery in a tertiary center, equipped for Urgent balloon atrial septostomy, for all patients with D-TGAIVS regardless of fetal echocardiographic features.

Can acute MH help? Perhaps



Szwast Anita (Orcid ID: 0000-0002-8734-6447)

Role of maternal hyperoxygenation testing to predict need for balloon atrial septostomy in fetal d-transposition of great arteries

cutpoint analysis, PFO size during MH testing ≤ 3.2mm predicted need for emergent BAS with sensitivity 93% and specificity 78%.

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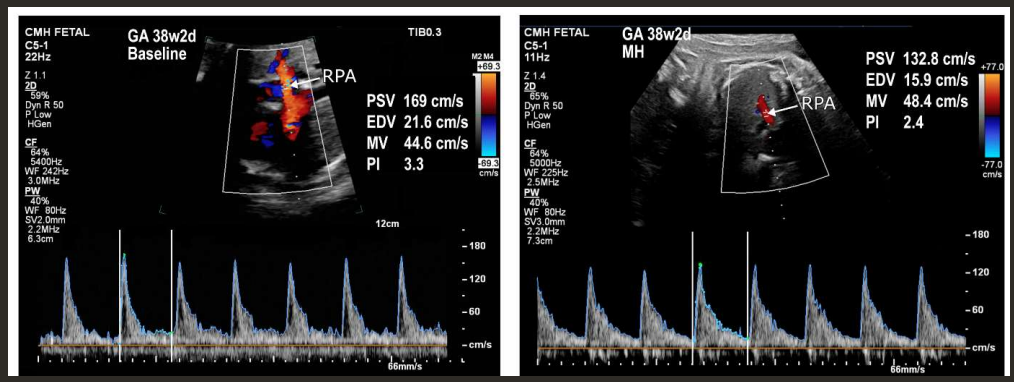
Pulmonary vasoreactivity in TGA

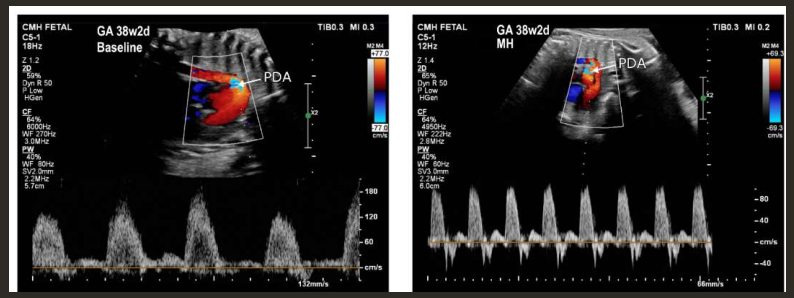
Persistent Pulmonary Hypertension of the Newborn With Transposition of the Great Arteries

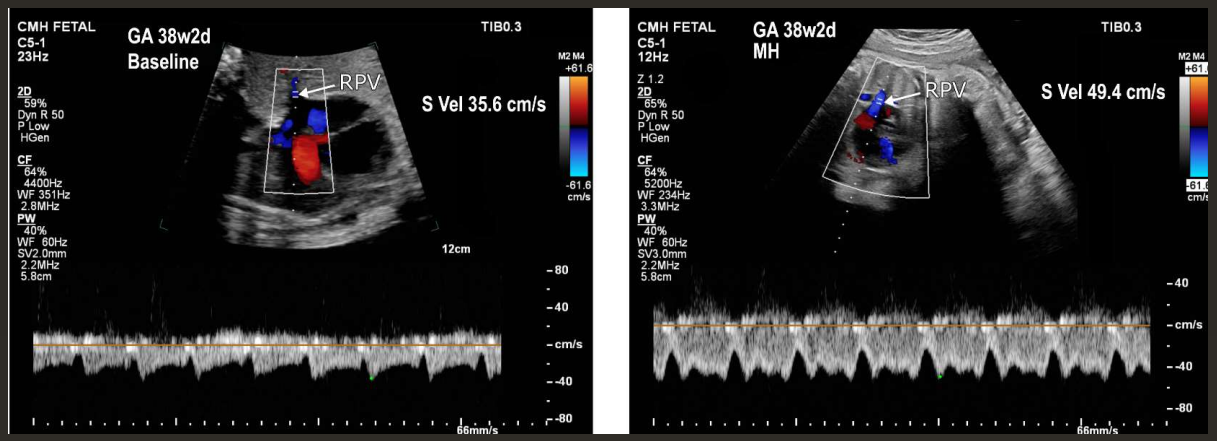
Marcus T. R. Roofthooft, MD, Klasina A. Bergman, MD, Tjalling W. Waterbolk, MD, Tjark Ebels, MD, PhD, Beatrijs Bartelds, MD, PhD, and Rolf M. F. Berger, MD, PhD

Departments of Paediatric Cardiology and Neonatology, Beatrix Children's Hospital, and Department of Thoracic Surgery, University Medical Centre Groningen, University of Groningen, Groningen, The Netherlands

Results. Fourteen out of 112 patients with TGA (12.5%) presented with associated PPHN. The PPHN occurred







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Postnatal course

- Delivery classification: Class III (possible hemodynamic instability)
- Induction at term
- Vaginal delivery
- Apgar scores 8 and 8
- Initial echocardiogram showed a 3.5*4.5mm PFO
- O2 saturations in the high 70s to 80s
- ASO on DOL 4

Case 3

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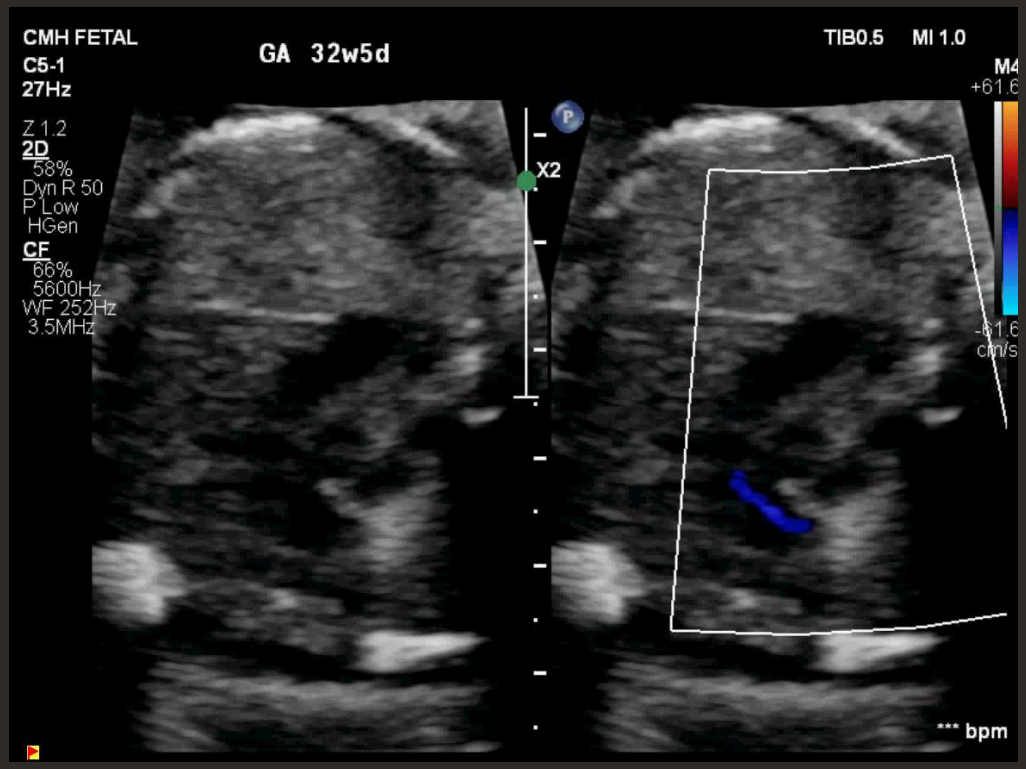
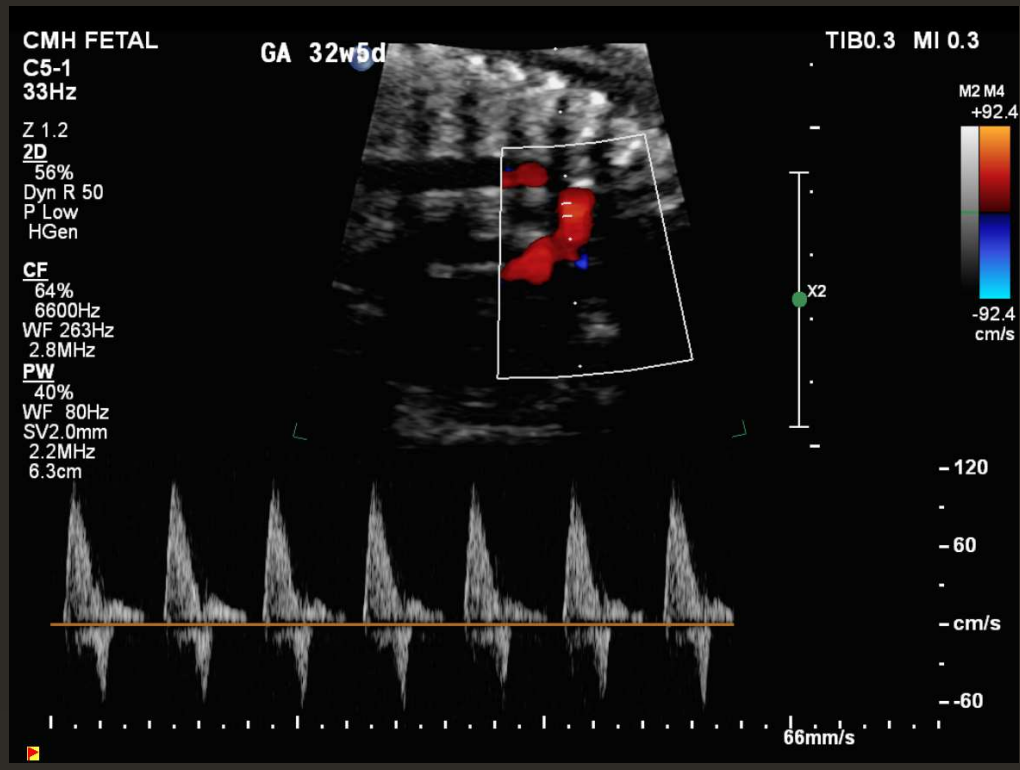
Case 3 aortic arch





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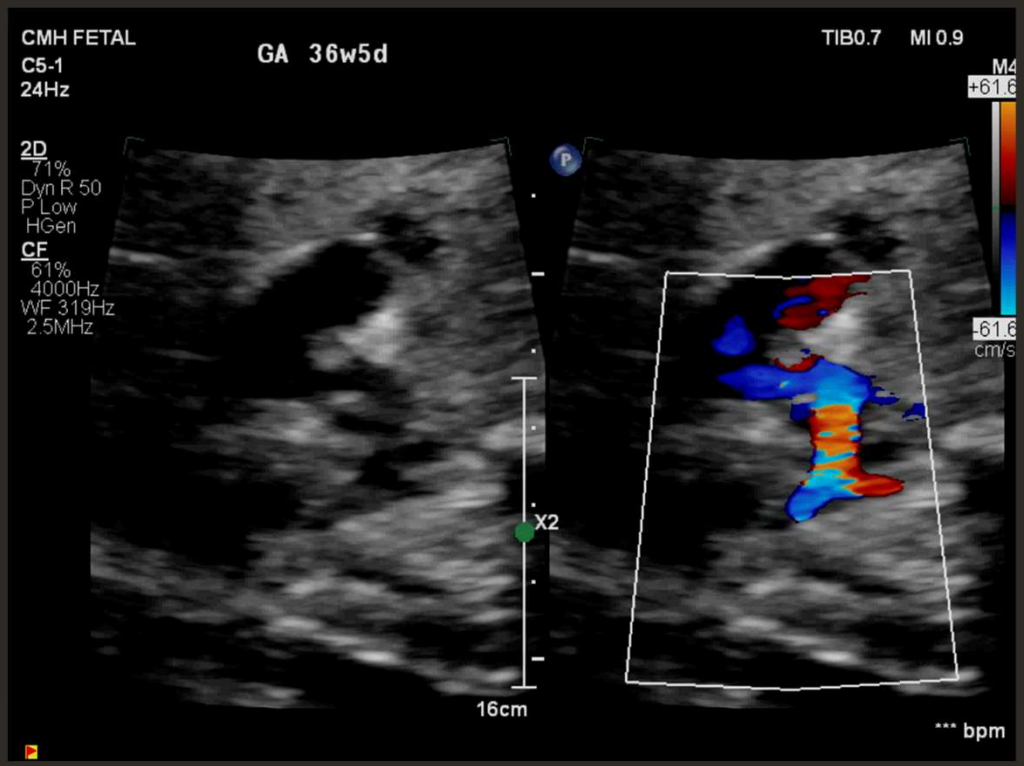
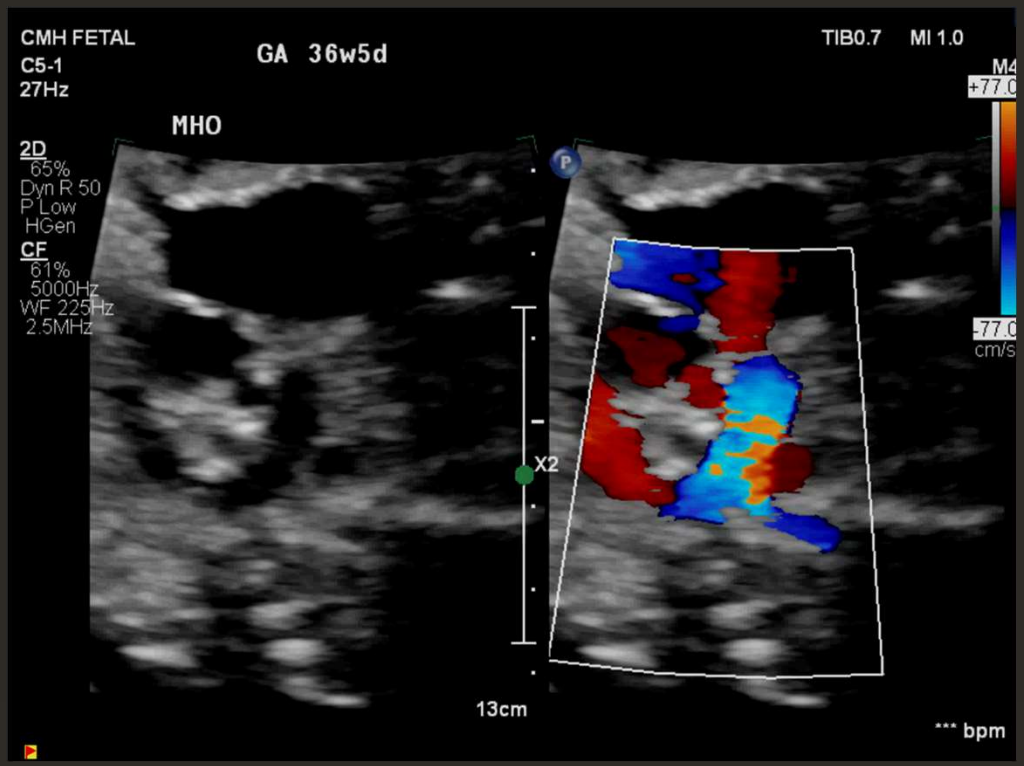
Case 3 Follow up arch with Acute MH





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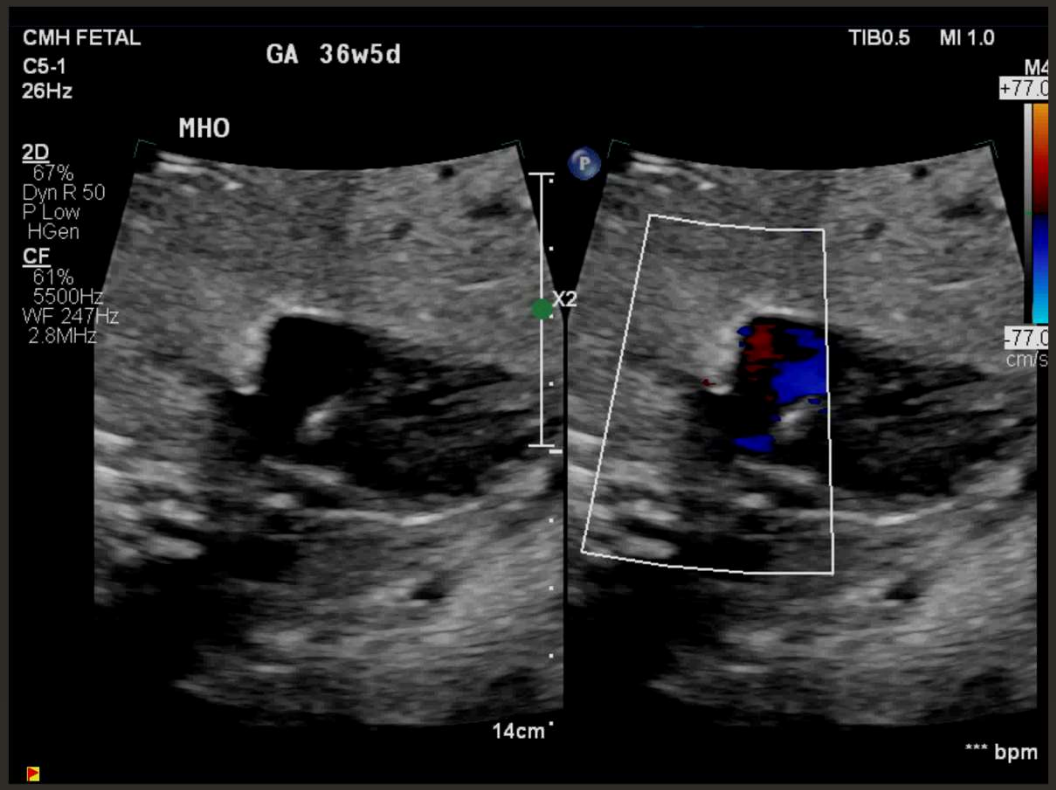
Case 3 Atrial septum with Acute MH



Ultrasound Obstet Gynecol 2015; 45: 664–669
Published online 4 May 2015 in Wiley Online Library (wileyonlinelibrary.com). **DOI:** 10.1002/uog.14688

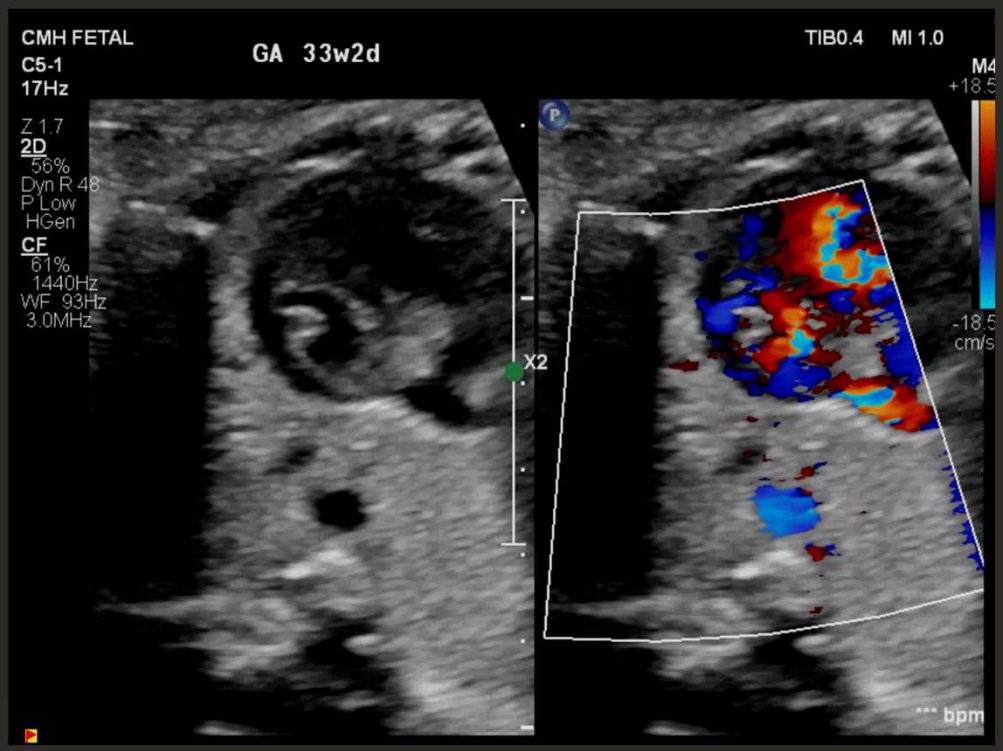
Maternal hyperoxygenation improves left heart filling in fetuses with atrial septal aneurysm causing impediment to left ventricular inflow

A. CHANNING*, A. SZWAST*†, S. NATARAJAN*, K. DEGENHARDT*†, Z. TIAN* and J. RYCHIK*†

Postnatal course

- Delivery classification: Class I (anticipated stable hemodynamics)
- Spontaneous vaginal delivery at term
- Apgar scores 9 and 9
- Initial echocardiogram showed a bicuspid aortic valve (well functioning), aortic isthmus at lower limits of normal, no posterior shelf and trivial PDA
- Being followed outpatient for BAV

Case 4



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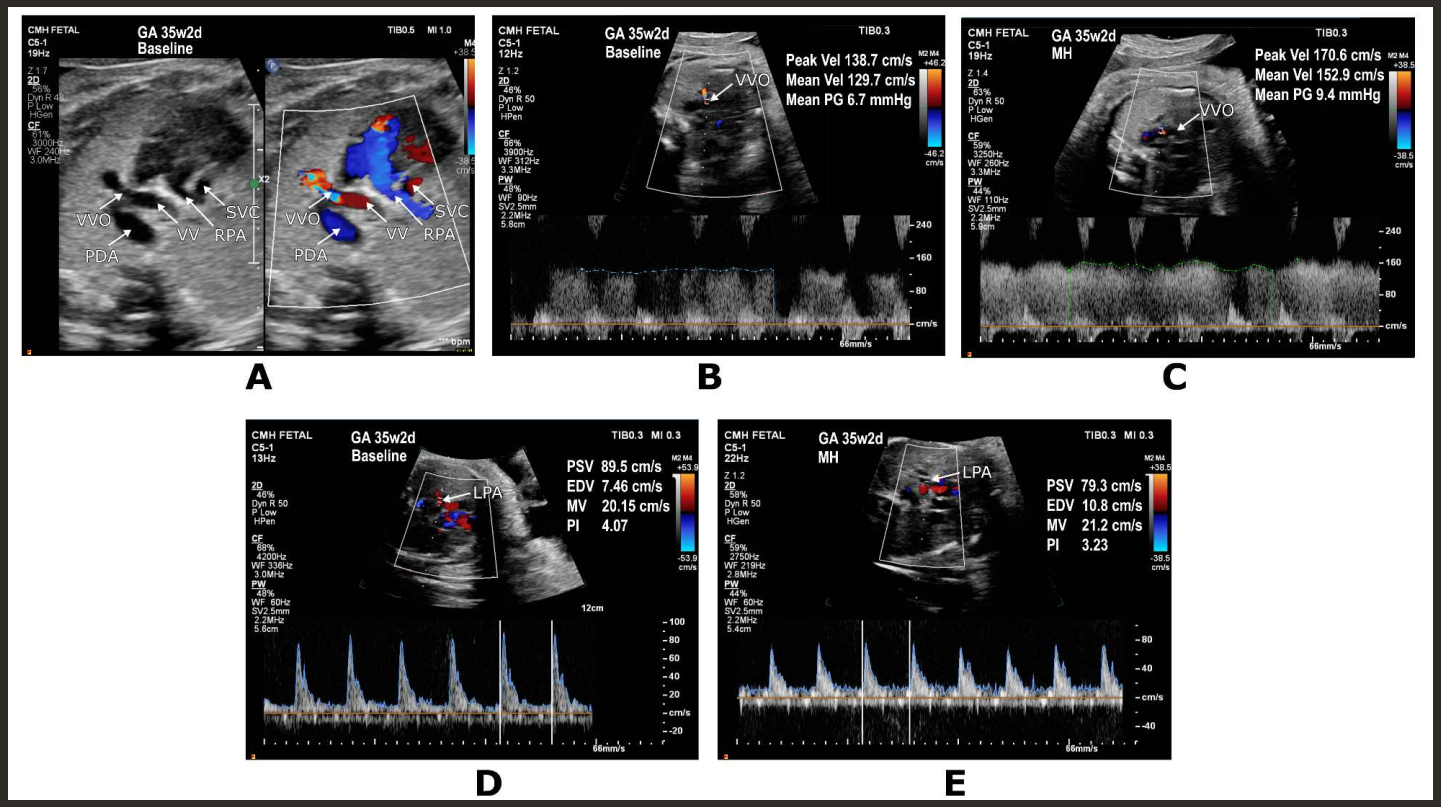
Acute MH in TAPVR



What can acute MH help answer (more data needed):

- Confirm obstruction
- If no pulmonary vasoreactivity:
- ? Perhaps need for immediate resuscitation
- ? Postoperative pulmonary hypertension

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Postnatal course

- Delivery classification: Class IV (anticipated hemodynamic instability)
- Planned C-Section at term
- Apgars 8,9. Initial O2 saturations in the 80s and then to the 70s within few minutes
- Postnatal echocardiogram confirmed diagnosis with mean vertical vein gradient of 14mmHg.
- TAPVC repair on DOL0
- Echocardiogram 2 weeks postoperatively with ½ systemic RVp

Conclusion

- Acute MH testing as an adjunct to standard fetal echocardiography can provide insight into fetal pulmonary vasculature
- It may help predict the postnatal hemodynamics and the transition of fetal circulation to postnatal circulation
- It can be helpful in risk stratification for fetuses at high risk of postnatal hemodynamic instability, e.g. HLHS with a concern for restrictive atrial septum, d-TGA, obstructive TAPVC

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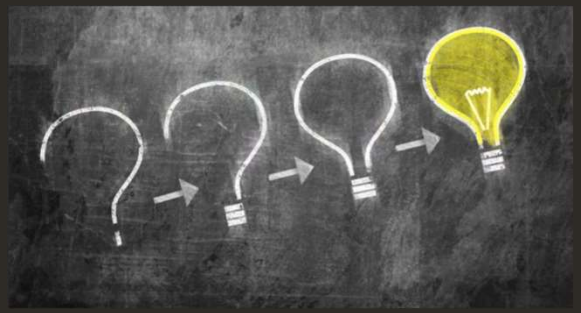
Thank you!



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