Advanced Imaging of Hemodynamic Changes in Pregnant Patients with Aortopathy: Predicting Aortic Risk

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Disclosures

Consultant for Medtronic, EndoRon.

Shareowner EndoRon, Voythus.

Why Does Imaging Matters in Pregnancy-Related Aortopathy ?

- Pregnancy-related aortic dissection is rare but lethal
- Mortality rates remain high despite advances
- Hemodynamic stress peaks during labor/delivery (80% increase in cardiac output)
- Early risk stratification can guide management and timing of delivery

Hemodynamic Changes in Pregnancy

- Normal Physiologic Adaptations:
  - Cardiac output ↑ up to 45% (peak 2nd-3rd trimester)
  - Stroke volume ↑ 30-50%
  - Heart rate ↑ 10-20 bpm
  - Blood volume ↑ 40-50%
  - Systemic vascular resistance ↓ 20-30%

Imaging Safety in Pregnancy

Modality	Safety Profile	Trimester Considerations
Echocardiography	No known risks, ALARA compliant	All trimesters
MRI (No contrast)	Safe (no gadolinium); avoid 1st trimester if possible	2nd/3rd trimester preferred
CT	Fetal dose 0.01-0.66 mGy; justify risk/benefit	Emergency

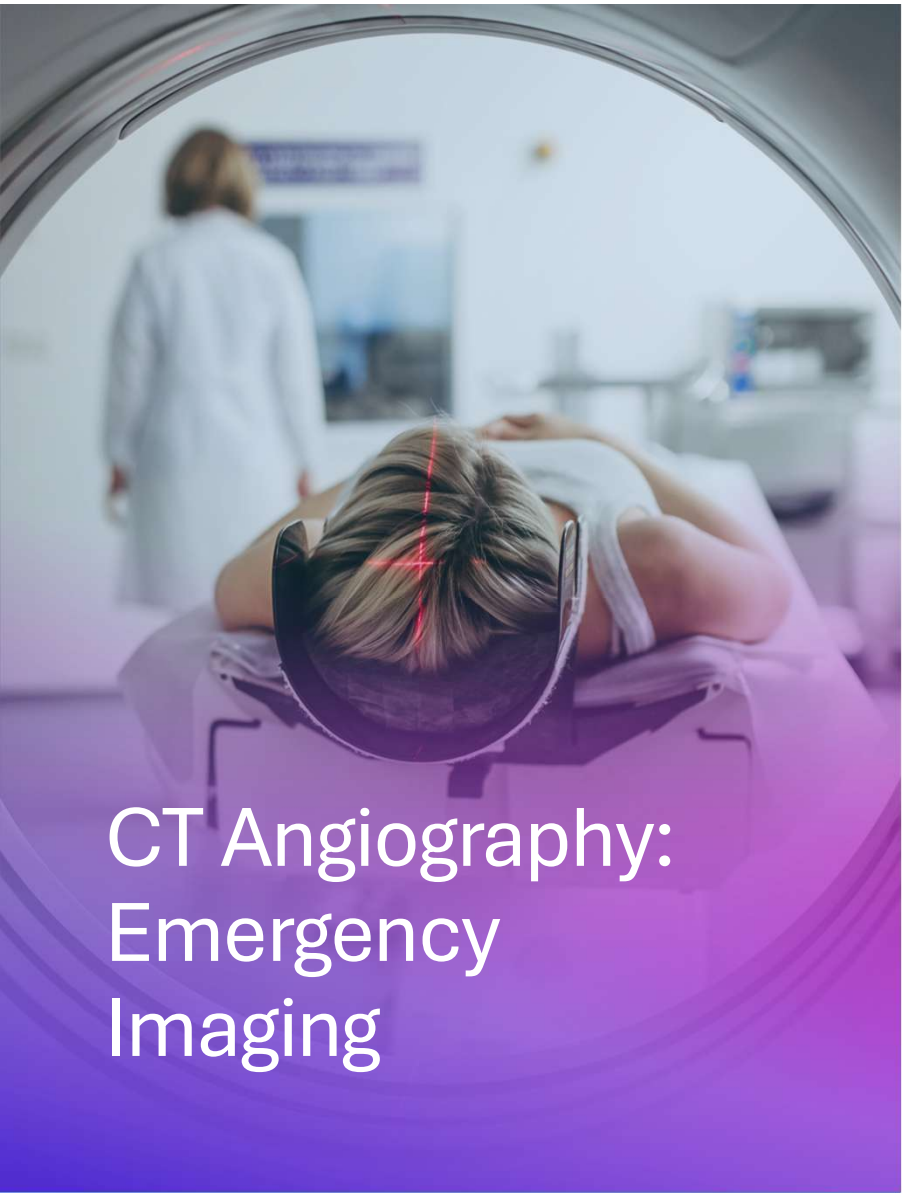
Transthoracic Echocardiography: Technical Approach

- Aortic root: Parasternal long-axis at sinuses of Valsalva, sinotubular junction, proximal ascending
- Measurements: Leading-edge to leading-edge technique, end-diastole
- Additional views: Suprasternal for arch visualization
- Doppler: Valve evaluation

Limitations: Descending thoracic and abdominal aorta not visualized

Advanced Echocardiographic Techniques

- Strain imaging: Aortic wall deformation analysis
- 3D echo: Volumetric aortic root assessment
- Tissue Doppler: Myocardial function under stress
- Speckle tracking: Early ventricular dysfunction



CT Angiography: Emergency Imaging

When Acute Dissection Suspected:

- Protocol: ECG-gated CT angiography with low-dose technique
- Diagnostic accuracy: 98-100% sensitivity, 98-99% specificity
- Fetal radiation: 0.01-0.66 mGy (below concern threshold of 50 mGy)
- Timing: <5 minutes from scanner to diagnosis

Risk-benefit clearly favors imaging when dissection is suspected

MRI: The Gold Standard

Coverage: Aortic root through iliac bifurcation (Inner edge to inner edge, end-diastole)

- Sequences:
    - Bright blood (SSFP) for anatomy
    - Black blood (T1/T2) for wall assessment
    - Cine imaging for distensibility
    - Phase-contrast for flow quantification

No gadolinium contrast needed for aortic assessment

Recommendation Table 60 — Recommendations for vascular imaging in Marfan syndrome

Recommendations	Class[a]	Level[b]
In patients with MFS, TTE is recommended:[70,171,1458,1459] • At least annually in patients with an aortic root diameter <45 mm in the absence of additional risk factors[c] • At least every 6 months in patients with an aortic root diameter <45 mm in the presence of additional risk factors[c] • At least every 6–12 months in patients with an aortic root diameter ≥45 mm in the absence of additional risk factors[c]	I	C
In patients without previous aortic surgery, complete peripheral vascular and thoracoabdominal aorta imaging by CMR or CCT and DUS is recommended at the first evaluation, and subsequently every 3–5 years if stable.[70,1455,1459]	I	C
In patients with MFS who have undergone aortic root replacement, surveillance imaging of the thoracic aorta by CMR (or CCT) is recommended at least every 3 years.[70,1458]	I	C

Table 34. Prophylactic Aortic Surgery Before Pregnancy in Women With Aortopathic Conditions

Condition	Surgical Threshold Before Pregnancy* by Aortic Diameter (cm) or Aortic Size Index (cm/m²)
Marfan syndrome	>4.5 cm
Marfan syndrome with risk factors (rapid aortic growth of ≥0.3 cm/y; family history of aortic dissection)	4.0–4.5 cm
Loeys-Dietz syndrome (attributable to pathogenic variants in *TGFBR1*, *TGFBR2*, or *SMAD3*)	≥4.0 cm
Loeys-Dietz syndrome (attributable to pathogenic variants in *TGFB2* or *TGFB3*)	≥4.5 cm
Nonsyndromic heritable thoracic aortic disease	≥4.5 cm†
Turner syndrome	≥2.5 cm/m²
Bicuspid aortic valve	≥5.0 cm‡

Recommendations for Delivery in Pregnant Patients With Aortopathy

COR	LOE	Recommendations
1	C-EO	1. In pregnant patients with a history of chronic aortic dissection, cesarean delivery is recommended.
1	C-EO	2. In pregnant patients with an aortopathy and an aortic diameter of <4.0 cm, vaginal delivery (when otherwise appropriate) is recommended.
2a	C-EO	3. In pregnant patients with a diameter of the aortic root, ascending aorta, or both, of ≥4.5 cm, cesarean delivery is reasonable.

Recommendations for Surgery Before Pregnancy in Women With Aortic Disease

COR	LOE	Recommendations
1	C-LD	1. In patients with Marfan syndrome and an aortic root diameter of >4.5 cm, aortic surgery before pregnancy is recommended.[1-4]
2b	C-LD	If the aortic root diameter is 4.0 cm to 4.5 cm, aortic surgery before pregnancy may be considered, especially if there are risk factors for aortic dissection (ie, rapid aortic growth of ≥0.3 cm/y or a family history of aortic dissection).[1,2,5-8]
2a	C-EO	2. In patients with Loeys-Dietz syndrome attributable to pathogenic variants in *TGFB2* or *TGFB3* and an aortic diameter of ≥4.5 cm, surgery before pregnancy is reasonable.
2b	C-EO	If the Loeys-Dietz syndrome is attributable to pathogenic variants in *TGFBR1*, *TGFBR2*, or *SMAD3*, and the aortic diameter is ≥4.0 cm, surgery before pregnancy may be considered.
1	C-EO	3. In patients with nsHTAD and an aortic diameter of ≥4.5 cm, surgery before pregnancy is recommended.
2b	C-EO	If the aortic diameter is 4.0 cm to 4.4 cm, surgery before pregnancy may be considered, depending on the molecular diagnosis, family history, and aortic growth rate.

Recommendations for Surgery Before Pregnancy in Women With Aortic Disease (Continued)

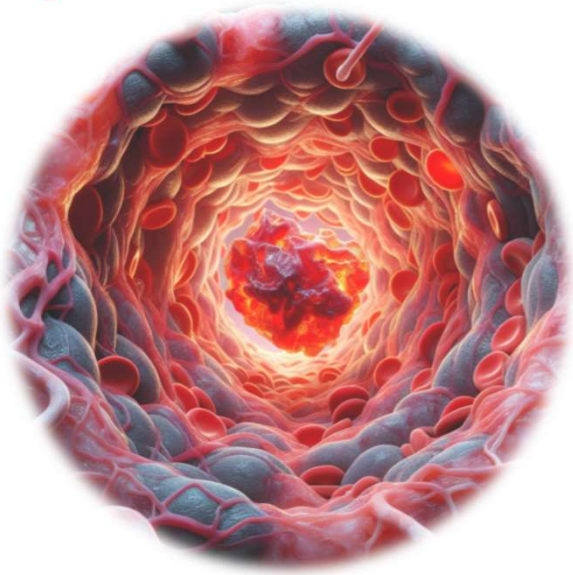
COR	LOE	Recommendations
1	C-LD	4. In patients with Turner syndrome and ASI of ≥2.5 cm/m², surgery before pregnancy is recommended.[9-11]
1	C-EO	5. In patients with a BAV (in the absence of Turner syndrome or an HTAD) and an aortic diameter of ≥5.0 cm, surgery before pregnancy is recommended.
1	C-EO	6. In patients with sporadic aortic root aneurysms, ascending aortic aneurysms, or both and a diameter of ≥5.0 cm, surgery before pregnancy is recommended.

Recommendation Table 62 — Recommendations for aortic surgery in Marfan syndrome

Recommendations	Class[a]	Level[b]
Surgery is indicated in patients with MFS who have aortic root disease with a maximal aortic sinus diameter ≥50 mm.[70,172,1466–1468]	I	B
Surgery to replace the aortic root and ascending aorta, using the valve-sparing surgery technique, is recommended in patients with MFS or related HTAD with aortic root dilatation when anatomical features of the valve allow its preservation and the surgeon has specific expertise.[70,1466,1469]	I	B
Surgery should be considered in patients with MFS who have an aortic root aneurysm with a maximal aortic sinus diameter ≥45 mm and additional risk factors.[c,1467,1469]	IIa	C
In patients with MFS and an aneurysm of the ascending aorta, aortic arch, descending thoracic aorta, or abdominal aorta of ≥50 mm, surgical replacement of the aneurysmal segment by a surgeon with specific expertise should be considered.[1467,1469]	IIa	C

So What is Beyond Anatomy ?

MRI :Tissue Characterization Beyond Anatomy



- T1 mapping: Detects myocardial diffuse fibrosis.
- T2 mapping: Detects myocardial edema or inflammation.
- Non-Contrast T1-Weighted imaging detects intramural hematoma.
- Diffusion imaging: Wall microstructural changes (ex vivo, early research)

Emerging possible biomarkers of aortic wall vulnerability

Aortic Distensibility and Stiffness by MRI

Quantifying Aortic Wall Properties:

Distensibility Formula:

- 2D Distensibility = $(A_{max} – A_{end\ dias}) / (A_{end\ dias}$ x pulse pressure)
- 3D Distensibility = $(V_{max} - V_{end\ dias})/ (V_{end\ dias}$ x pulse pressure)

Clinical Significance:

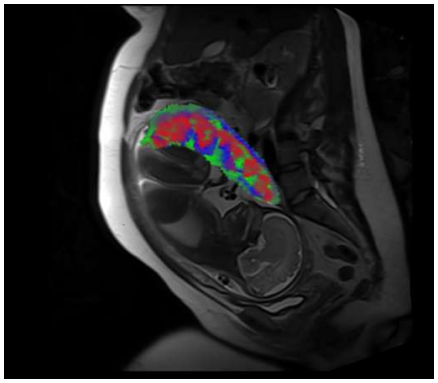
- Decreased distensibility = increased stiffness
- *Predicts all cause mortality independent of conventional risk factors.*
- In high-risk pregnancies aortic and central arterial distensibility are reduced compared to normal pregnancies.

4D Flow MRI: Hemodynamic Visualization

Time-resolved 3D phase-contrast MRI technique that captures three-directional blood flow velocity across an entire vascular volume over the cardiac cycle.

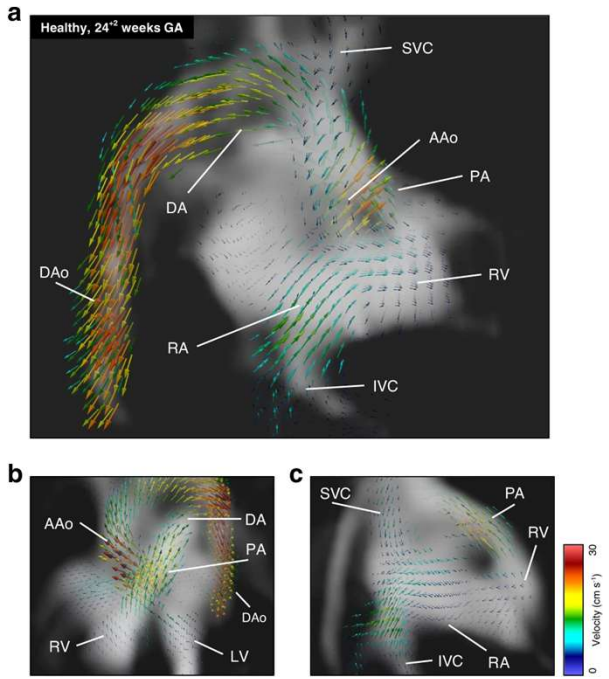
- 3D velocity vector field throughout the cardiac cycle
- Wall shear stress quantification (model-based estimates)
- Flow pattern visualization (helical flow, vortices)
- Pressure gradient estimation (model-based estimates)

Fetal 4D Flow MRI



Emerging Technology for Fetal Cardiovascular Assessment:

- Visualizes 3D blood flow in fetal heart and great vessels
- Quantifies flow through the aorta, pulmonary artery, and ductus arteriosus
- Detects congenital heart disease (e.g., coarctation, HLHS)
- Feasible in third trimester with motion correction



Roberts, T.A., van Amerom, J.F.P., Uus, A. *et al.* Fetal whole heart blood flow imaging using 4D cine MRI. *Nat Commun* **11**, 4992 (2020). https://doi.org/10.1038/s41467-020-18790-1

4D Flow MRI: Uterine Artery Assessment

Novel Placental Perfusion Evaluation:

- Quantifies bilateral uterine artery flow
- Measures the pulsatility index and resistivity index
- Associated with risk of preeclampsia and IUGR; MRI-based markers are being studied for prediction.
- Visualizes entire vessel course (beyond Doppler US limitations)

Wall Shear Stress (WSS) Analysis

- Normal pregnancy: increased flow with vascular remodeling that tends to normalize WSS.
- Aortopathy: Focal areas of elevated WSS associated with regions of medial degeneration.
- 4D flow MRI quantification: Maps stress distribution along the entire aorta
- Clinical application: May help identify vulnerable segments for surveillance

MRI Predictors Beyond Diameter

- Aortic growth rate: CMR highly reproducible, can detect growth >2mm with high precision

- Pulse wave velocity: >10 m/s reflects markedly increased aortic stiffness and higher CV risk.

- Aortic strain: Reduced aortic strain is associated with a higher complication risk.

- Flow displacement: Reveals abnormal eccentric/helical flow patterns in aortopathy

- Wall thickness changes: Reflects vascular remodeling and subclinical disease.

- Abnormal flow patterns may precede and potentially drive diameter changes?

Is There a Role for 4 D MRI in Pregnant Patients with Aortopathy ?

Artificial Intelligence in Aortic Imaging

Future of Risk Prediction

AI segmentation: Automated aortic measurements

Machine learning models: Integrate diameter, growth, biomechanics

Radiomics: Texture analysis of the aortic wall

Predictive algorithms: Personalized risk scores

Early studies show 85-90% accuracy for CT-based detection of aortic dissection.

Conclusions

- Current time:
  - Multimodality approach optimizes risk stratification
  - MRI is the gold standard for complete aortic assessment without radiation
  - Serial echo enables frequent monitoring
  - CT for emergencies
- The Future
  - Further research to improve gaps in knowledge
  - We need imaging data beyond diameter
  - Combined imaging-biomarker risk models
  - AI-enhanced automated measurements and risk prediction
- ***International imaging registries for pregnancy aortopathy***

Thank You!

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