# Reducing the Risk of Heart Block at the Time of Cardiac Surgery

Elizabeth DeWitt, MD

Associate Cardiologist, Division of Electrophysiology / Department of Cardiology

Boston Children's Hospital

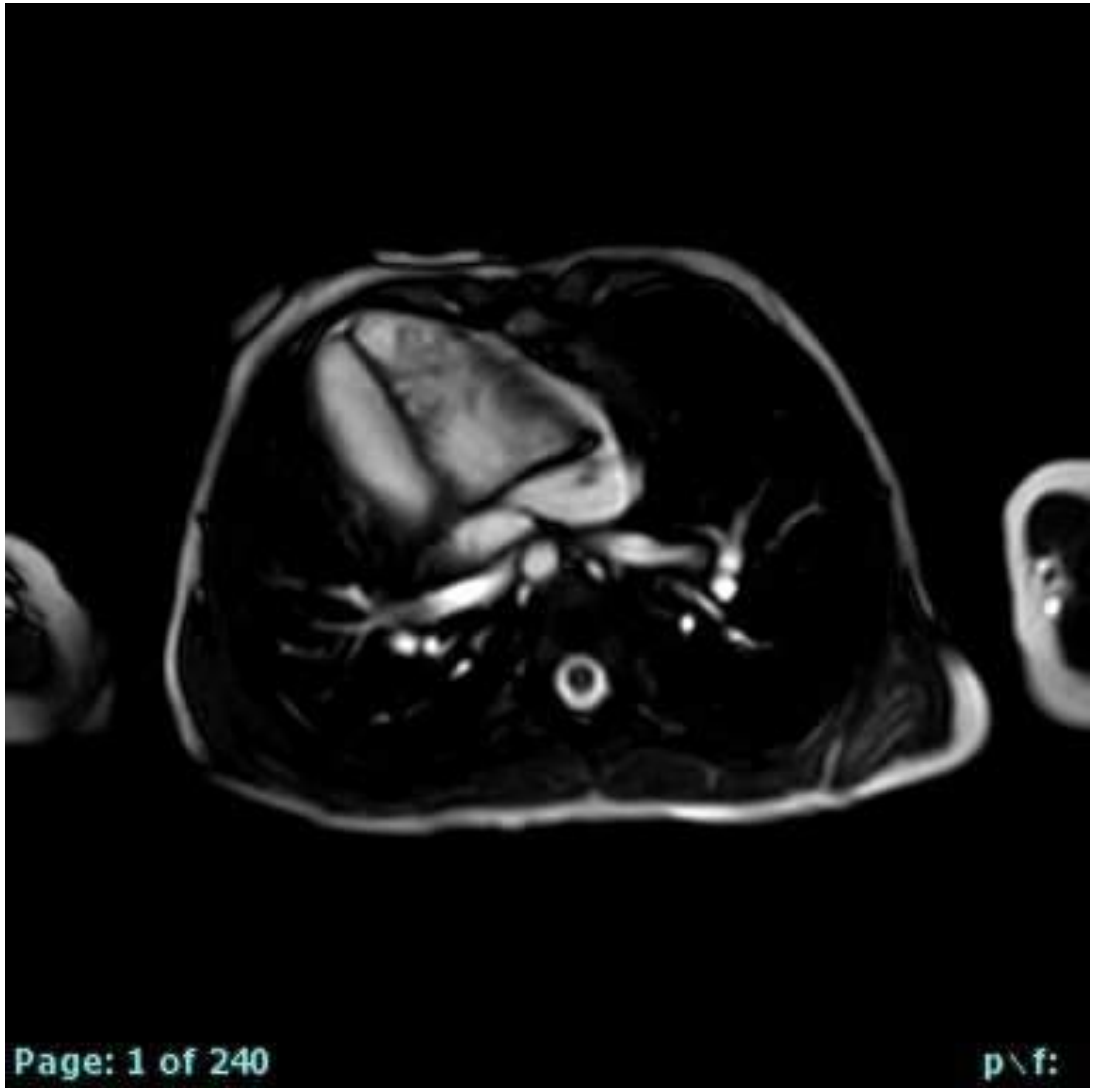
February 20, 2025

# Disclosures

- None.

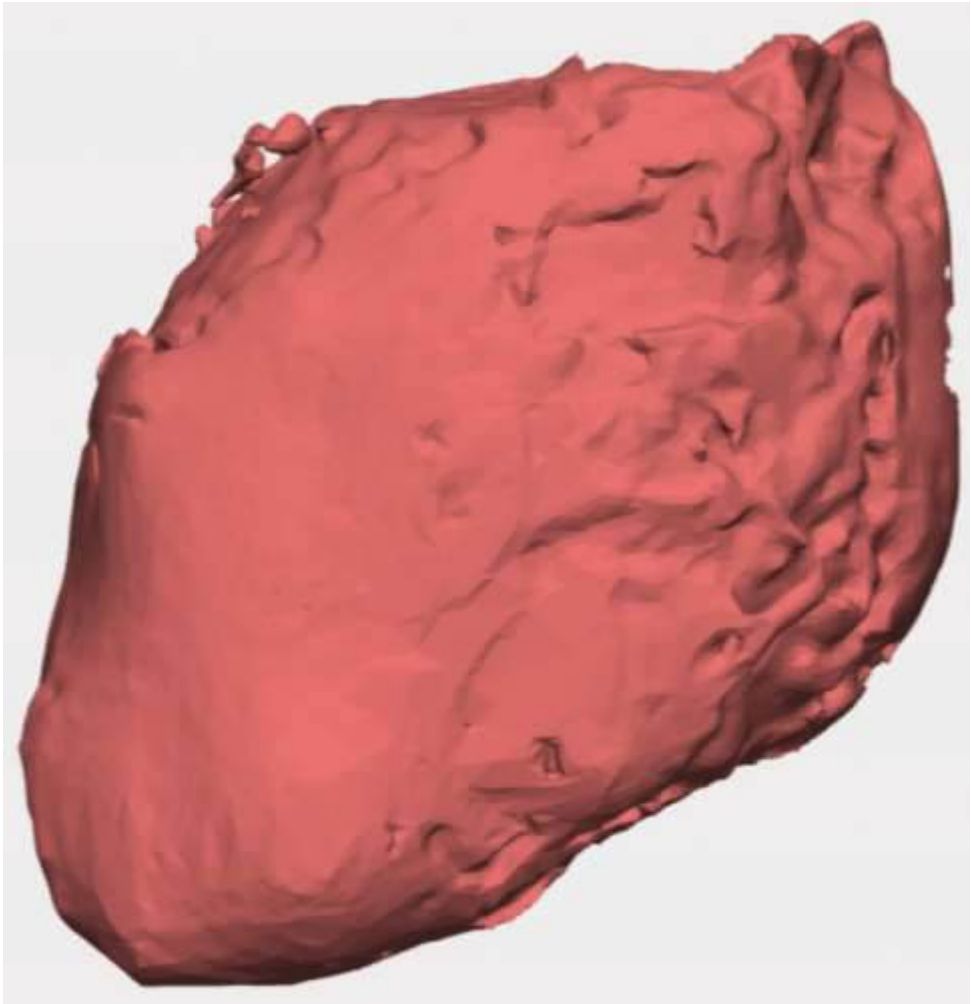
# Case Example

- 3 year-old:
  - Heterotaxy/ asplenia, dextrocardia, {A,L,L}
  - Complete atrioventricular canal
  - Double-outlet right ventricle
  - Pulmonary atresia
  - Total anomalous pulmonary venous connection
- Prior single-ventricle palliation (TAPVC repair, bilateral BDGs)
- Presenting for consideration of biventricular repair



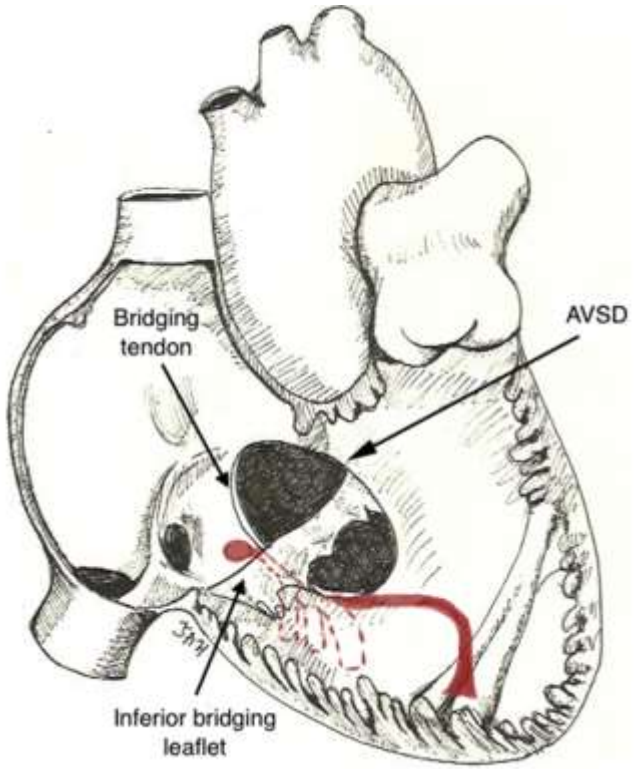
# Case Example – Surgical Planning

- Given LV/ RV volumes, felt to be a candidate for biventricular conversion
- Proposed repair: takedown bilateral bidirectional Glenn, atrial switch, CAVC repair, LV to Ao baffle, and RV-PA conduit.
- Where would conduction be most likely to be located?

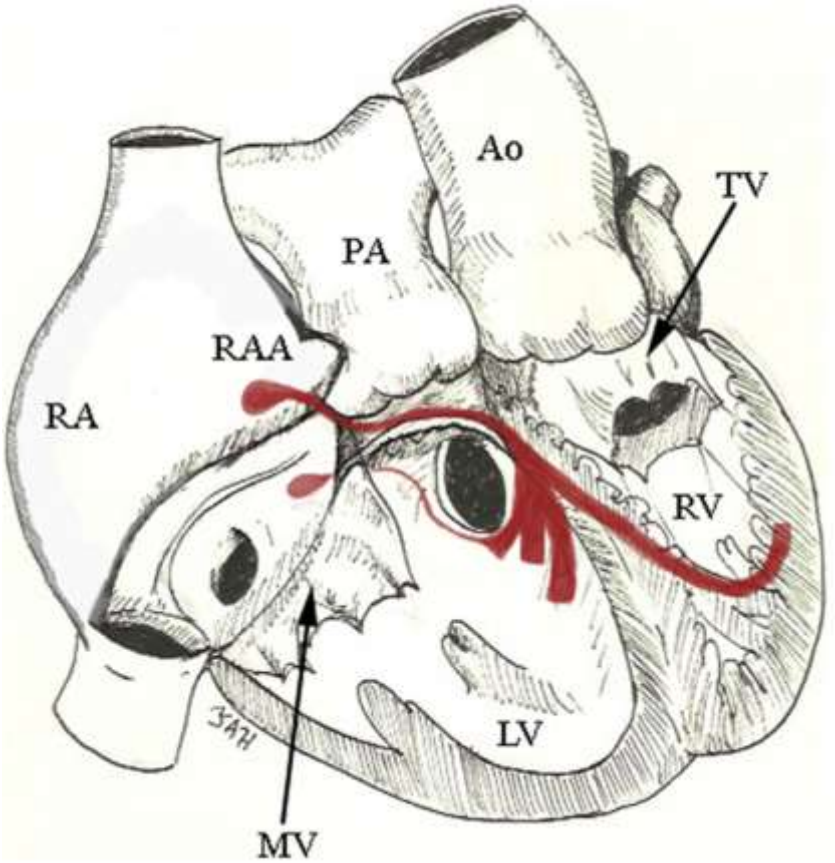


# Conduction Anatomy – *"Conventional" Beliefs*

## CAVC defects→ INFERIOR CONDUCTION



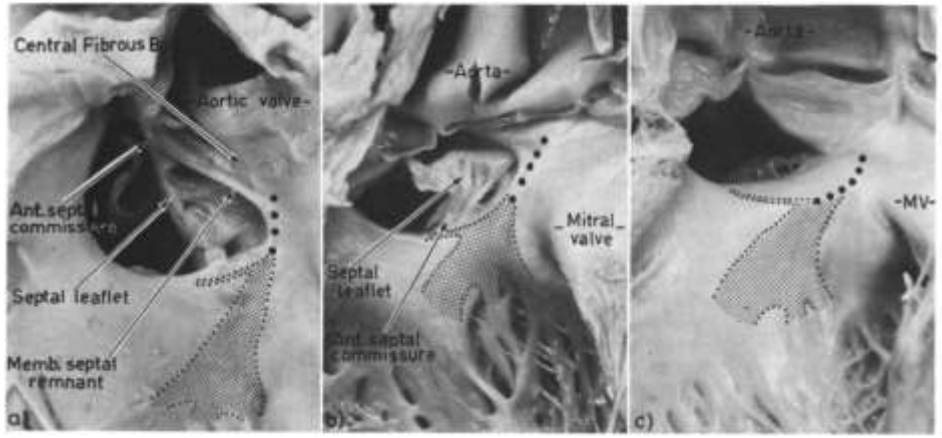

## L-Looping → SUPERIOR CONDUCTION

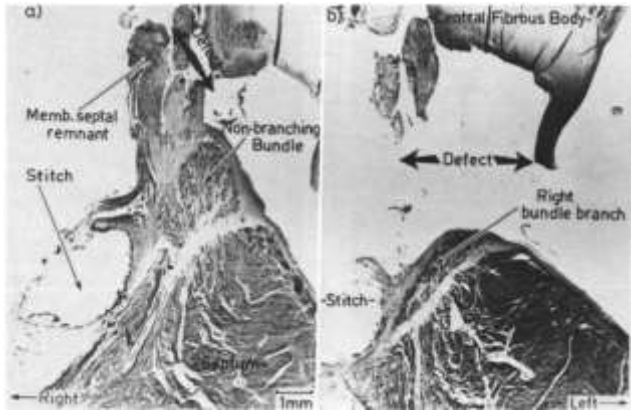



Moore JP, Aboulhosn JA. Introduction to the congenital heart defects: anatomy of the conduction system. *Card Electrophysiol Clin*. 2017;9:167-75.

J THORAC CARDIOVASC SURG 79:244-255, 1980

# Surgical anatomy and atrioventricular conduction tissues of hearts with isolated ventricular septal defects



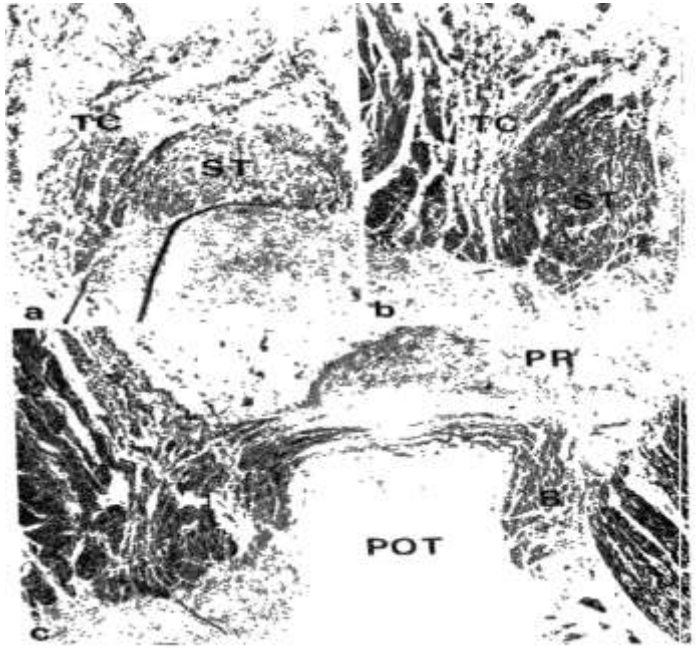




THE LANCET, JUNE 9, 1973

# THE CONDUCTING SYSTEM IN CONGENITALLY CORRECTED TRANSPOSITION

R. H. ANDERSON
*University Department of Anatomy, Stopford Building, Manchester M13 9PT*

R. ARNOLD J. L. WILKINSON
*University Department of Child Health, Liverpool L69 3BX*



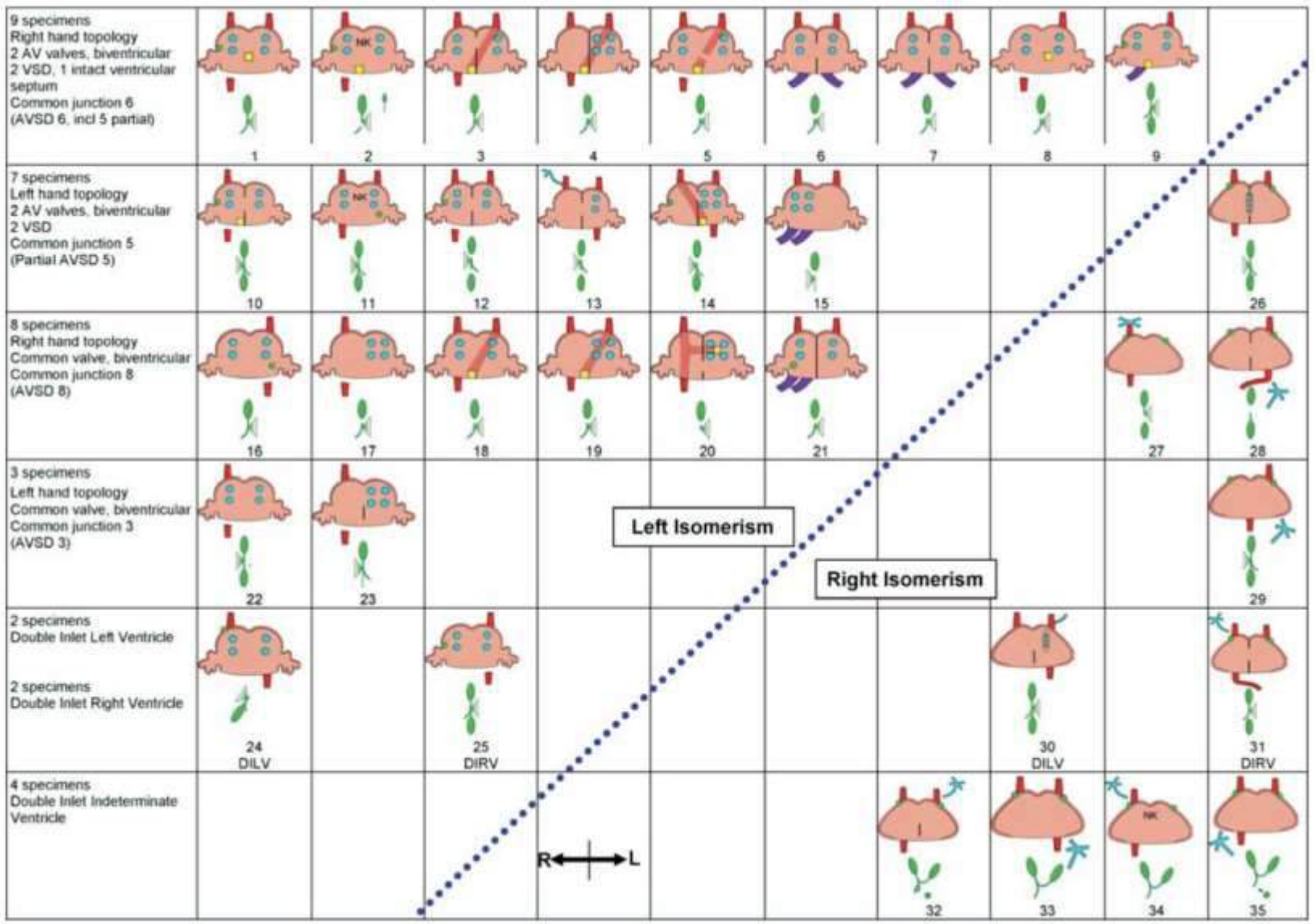
# Atrioventricular Node Characteristics in Heterotaxy

The diverse cardiac morphology seen in hearts with isomerism of the atrial appendages with reference to the disposition of the specialised conduction system

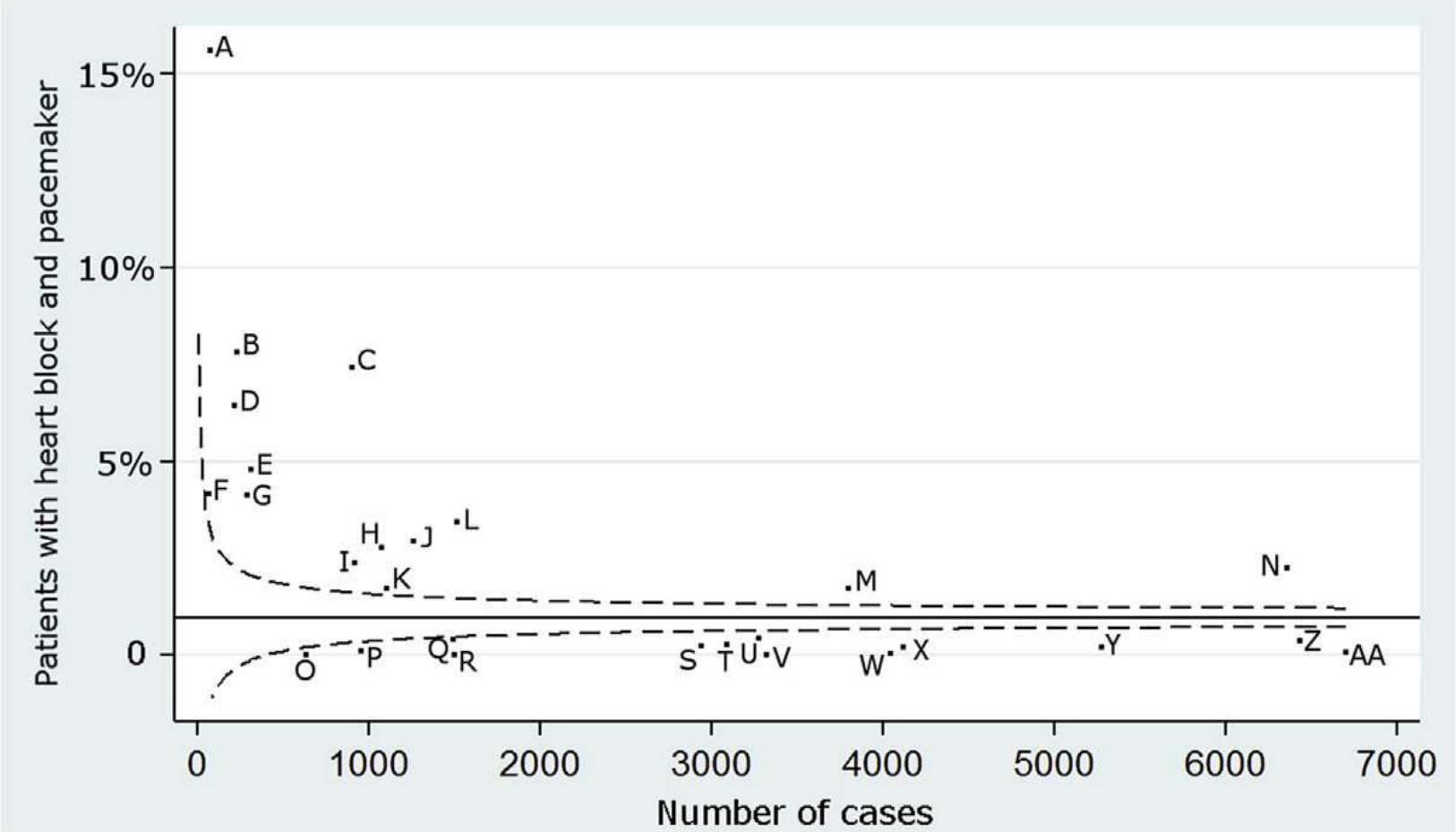
Audrey Smith,[1] Siew Yen Ho,[2] Robert H. Anderson,[1] M. Gwen Connell,[3] Robert Arnold,[3] James L. Wilkinson,[4] Andrew C. Cook[1]

*Cardiol Young 2006; 16: 437–454*

**Ventricular topology** & **AV connection** define atrioventricular conduction



# Incidence of Postoperative Heart Block by Operation




A Double Switch
B TVR
C MVR
D Atrial switch/VSD
E Rastelli
F Ebstein < 30D
G Konno
H Sub AS
I Ross
J AVR
K Coactation/VSD
L ASO/VSD
M Mitral valvuloplasty
N CAVC
O PAPVC
P TAPVC>30d
Q Norwood/HLHS
R PDA>30D
S PV replacement
T IAA/VSD
U RV->PA conduit
V Coactation >30d
W Coactation <30d
X Glenn
Y Fontan
Z BT Shunt
AA Secundum ASD

Lieberman et al, JTCVS 2016 152:197-202

# Postoperative Heart Block in Heterotaxy Patients

**Biventricular Repair in Heterotaxy Patients**

**Zeena Makhija, MD[1], Ashutosh Marwah, MD[2], Smita Mishra, MD[2], Jay Kumar, MD[3], Apoorva Goel, MD[3], and Rajesh Sharma, MCh[1]**

World Journal for Pediatric and Congenital Heart Surgery
2015, Vol. 6(2) 195-202

- 20 HTX patients undergoing biventricular repair (2007–2012)
- **25% required PPM for postoperative complete heart block**

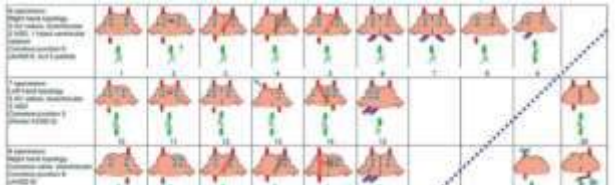
**Biventricular repair in patients with heterotaxy syndrome**

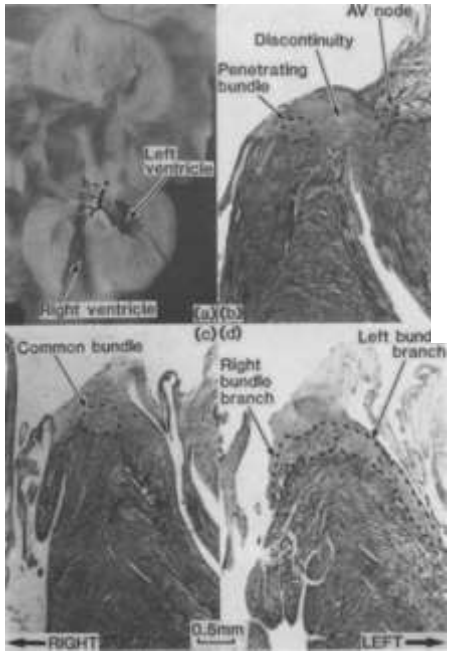
H. G. Lim, MD,[a] E. A. Bacha, MD,[a] G. R. Marx, MD,[b] A. Marshall, MD,[b] F. Fynn-Thompson, MD,[a] J. E. Mayer, MD,[a] P. Del Nido, MD,[a] and F. A. Pigula, MD[a]

The Journal of Thoracic and Cardiovascular Surgery • Volume 137, Number 2

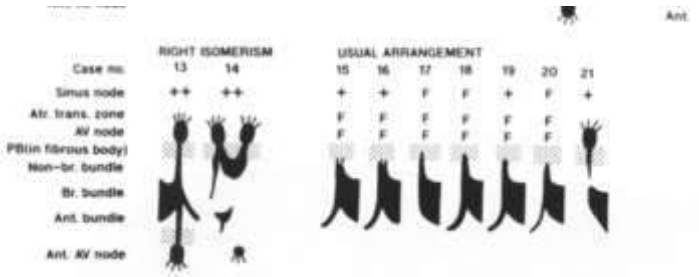
- 91 HTX patients undergoing biventricular repair (1990-2007)
- **14% required PPM for postoperative high grade AV block**

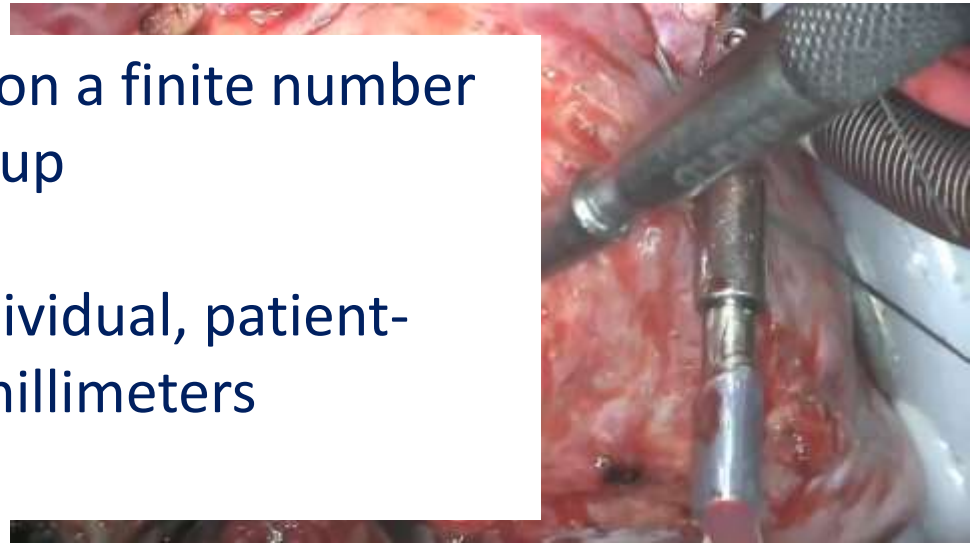
# Why do we still get heart block in these patients?



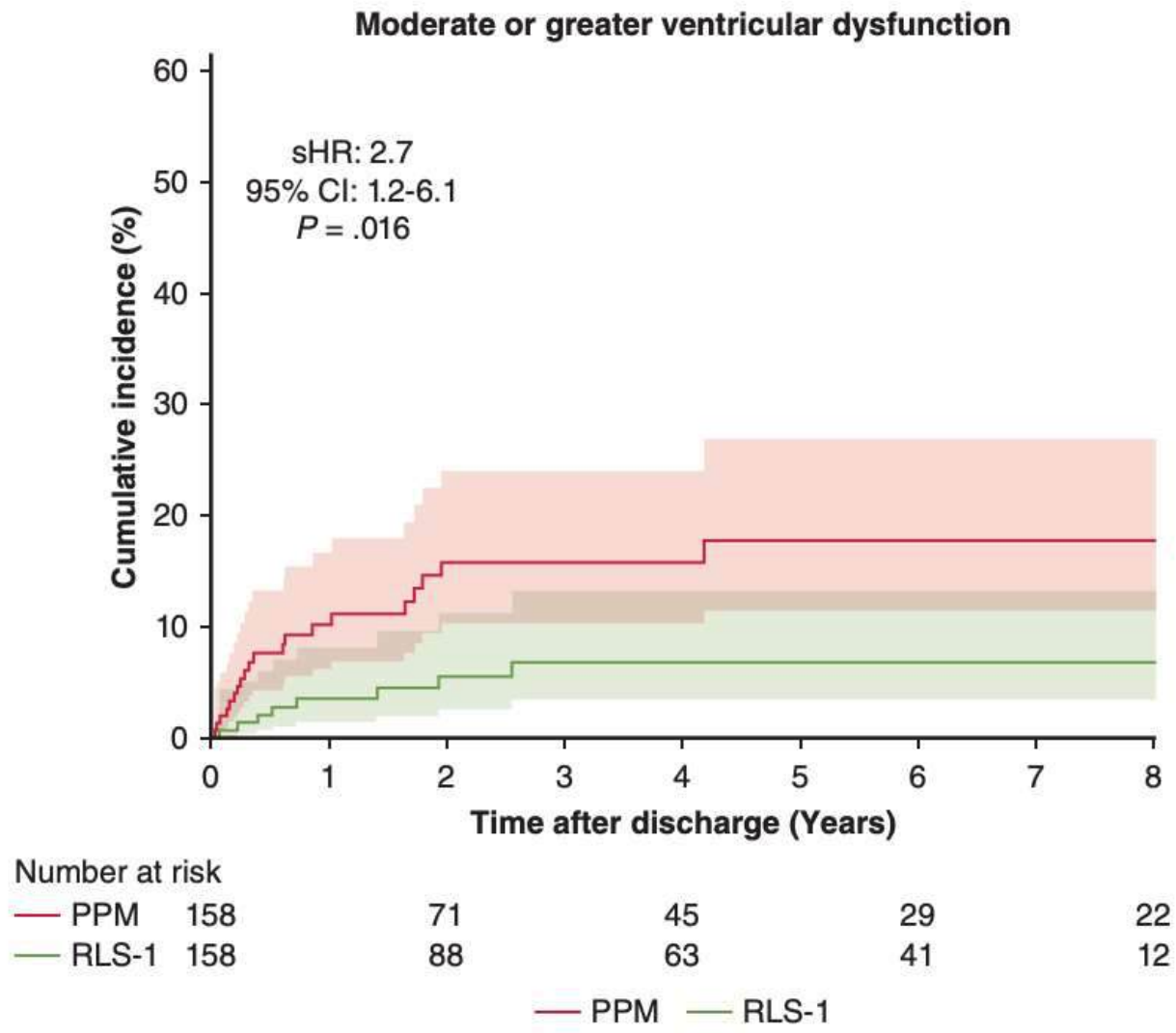

- Inherent limitations in studies relying on a finite number of hearts to represent “rules” for a group
- Fundamentally cannot account for individual, patient-specific variability, where even a few millimeters difference may be critical



# Burden of Chronic Pacing

- Increased mortality[1]
- Increased risk of moderate or greater ventricular dysfunction in follow-up[2]
- Pacemaker-induced cardiomyopathy[3]
- Device/lead failures requiring reintervention[4]
- Coronary compression[5]
- Increased costs during initial hospitalization and length of stay[6]

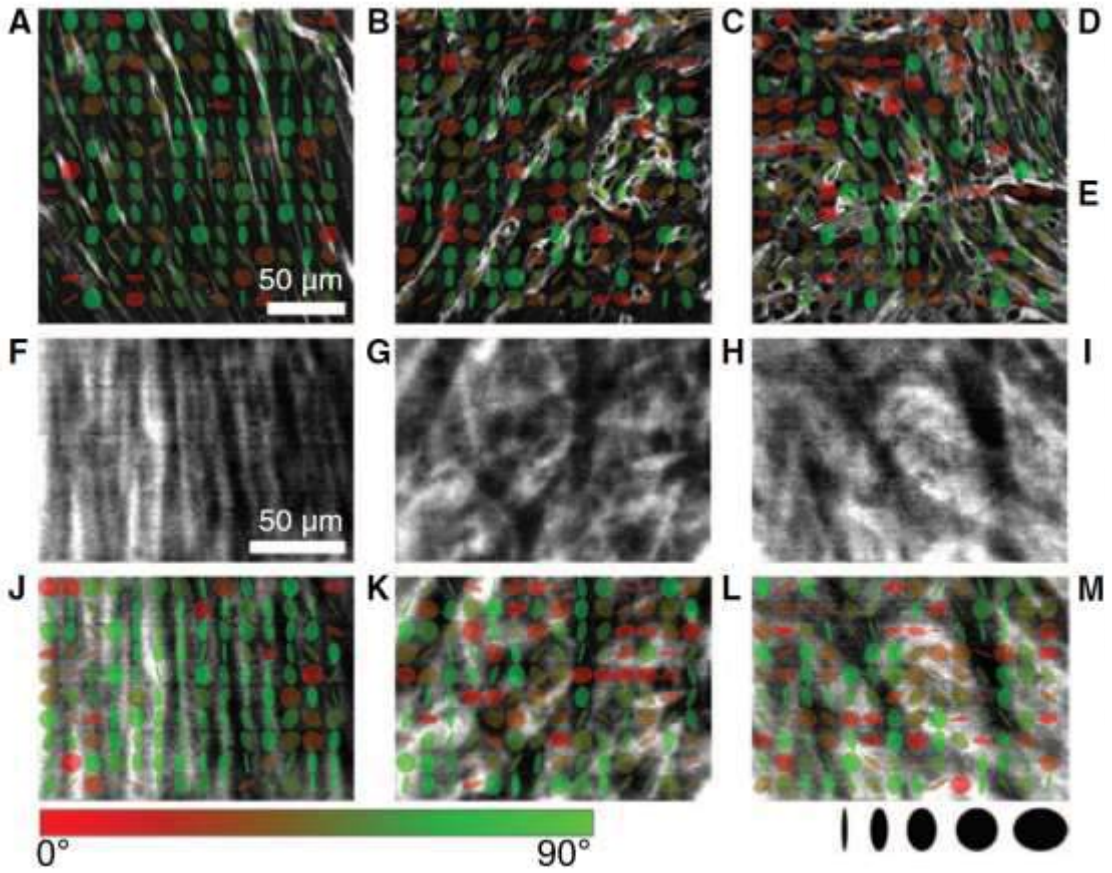


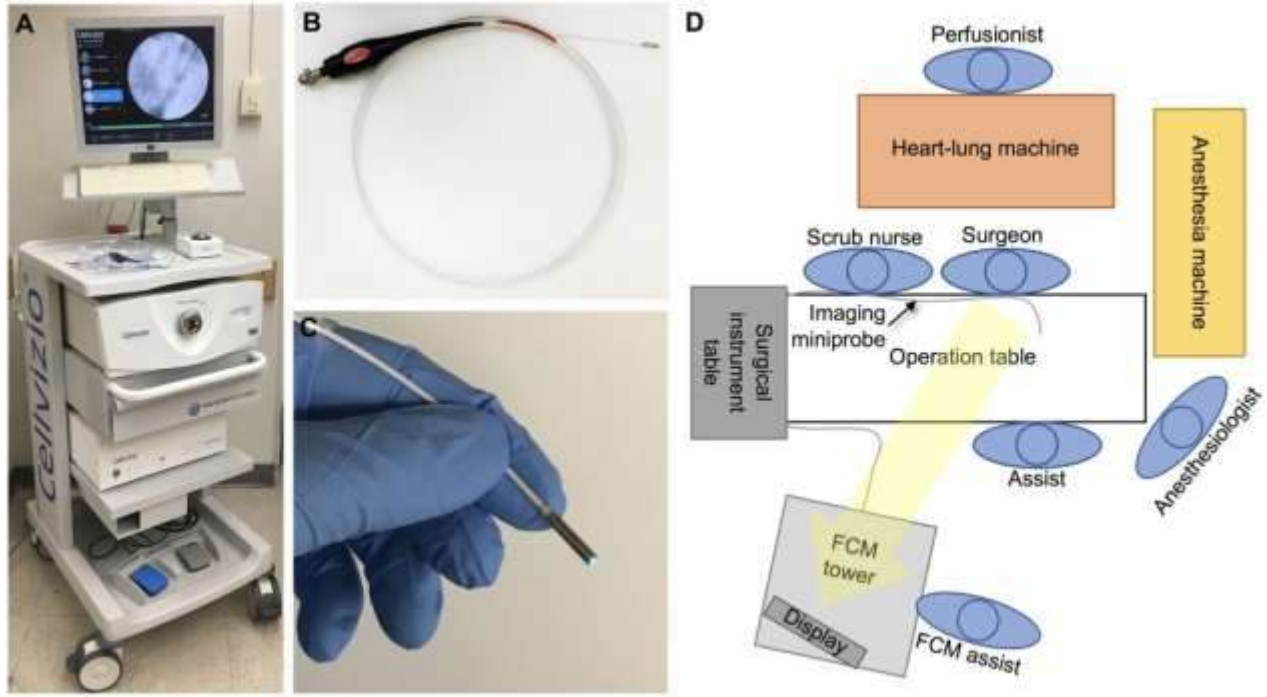


[1] Liberman L et al. *J Thorac Cardiovasc Surg*. 2016;152:197-202.
[2] Zhang W, et al, *J Thorac Cardiovasc Surg.* 2025;169:411-9.
[3] Bulic A, et al. *Heart Rhythm*. 2017;14:853-7.
[4] Fortescue E, et al. *Heart Rhythm*. 2004;1:150-9.
[5] Mah DY, et al. *Heart Rhythm.* 2018;15:1439-47.
[6] Mondal, et al. *JAMA Network Open*. 2023;6(11):e2341174.

# How can we avoid postoperative heart block?

# Intraoperative microscopic tissue evaluation

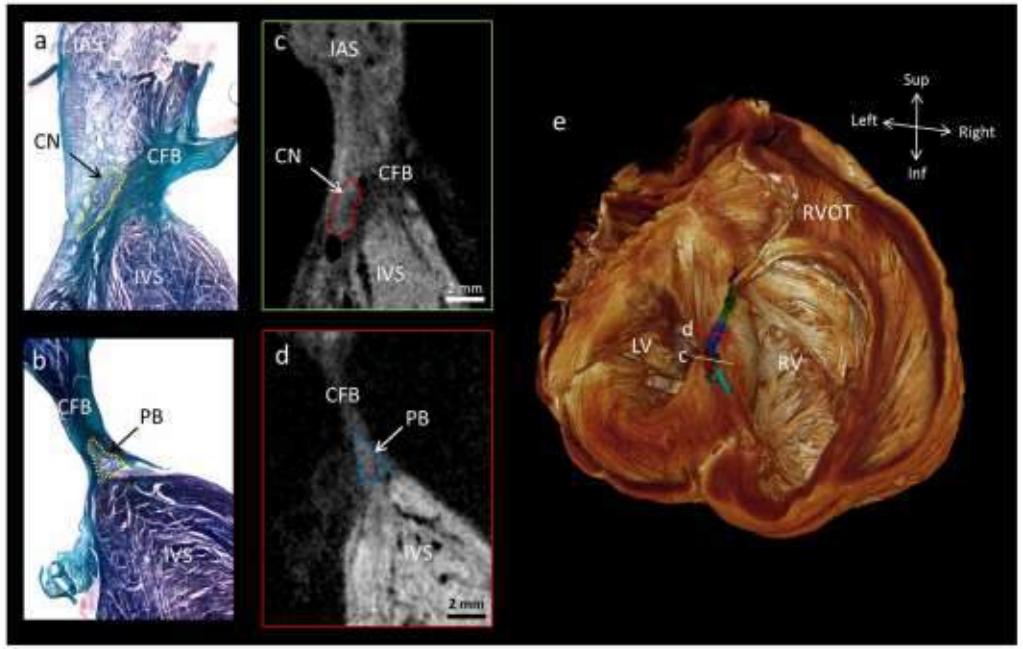



Kaza AK et al Eur J Cardiothorac Surg 2020;58:261–8.
Circ Cardiovasc Imaging 2013;6:739-746

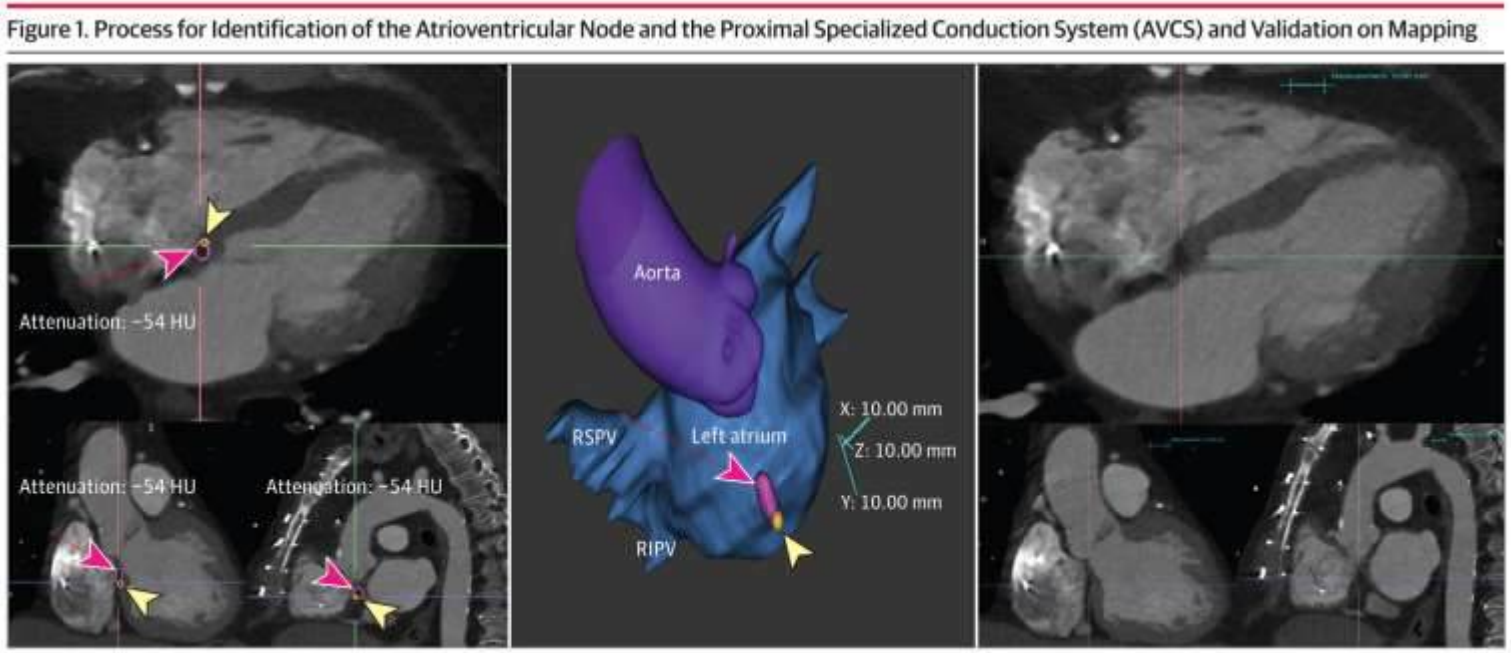
# Imaging Approaches

## Micro CT



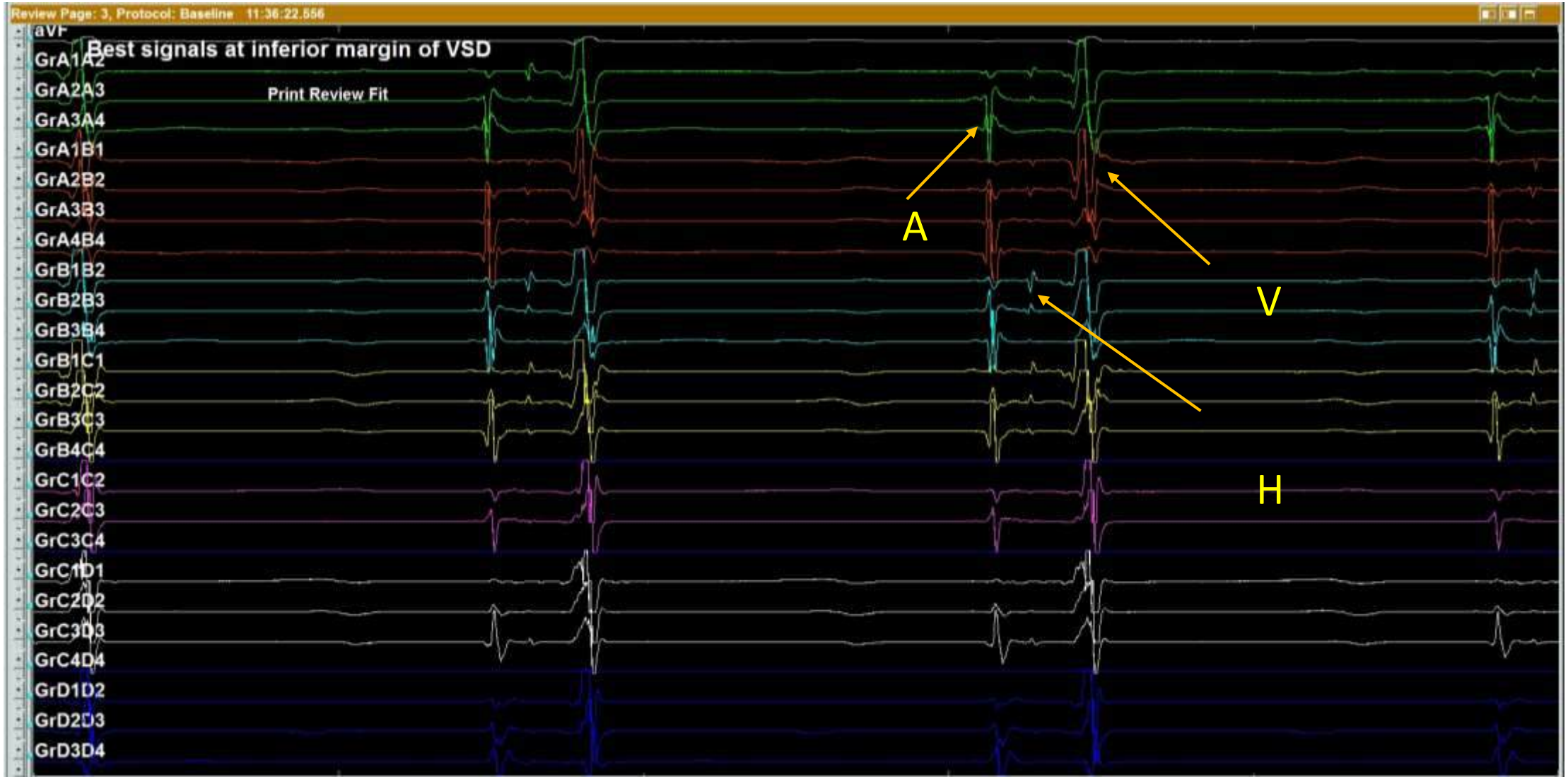

Sci Rep. 2017 Aug 3; 7(1):7188.

## CT evaluation of AV nodal tissue




Khoshknab et al JAMA Cardiology 2024 July 24
doi:10.1001/jamacardio.2024.2012

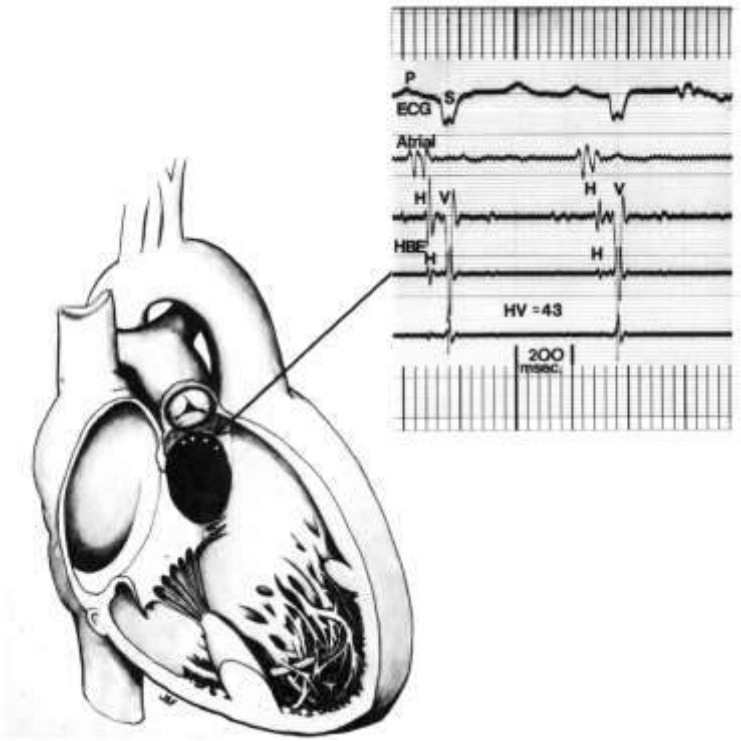
# Electrical Approach



# Historical Experience with Intraoperative Mapping

## Intraoperative Recording of Specialized Atrioventricular Conduction Tissue Electrograms in 47 Patients

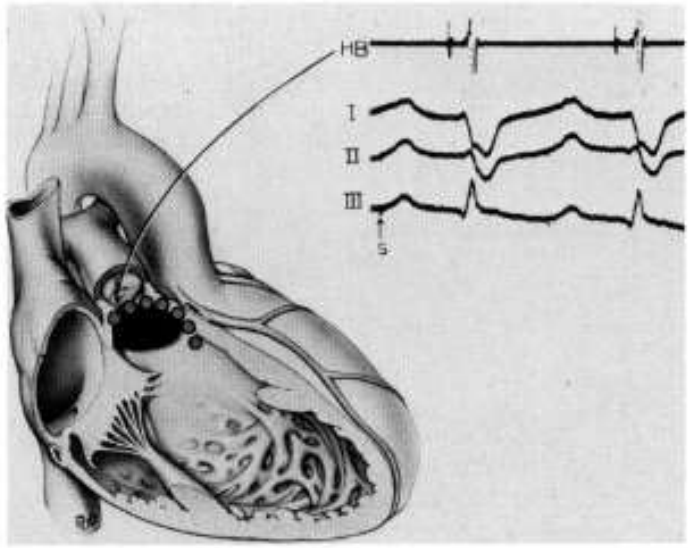
MACDONALD DICK, II, M.D., WILLIAM I. NORWOOD, M.D., CARL CHIPMAN, B.S., AND ALDO R. CASTANEDA, M.D.




## Electrophysiologic Identification of the Specialized Conduction System in Corrected Transposition of the Great Arteries

*By* JOEL KUPERSMITH, M.D., EHUD KRONGRAD, M.D., WELTON M. GERSONY, M.D., AND FREDERICK O. BOWMAN, JR., M.D.

*Circulation, Volume 50, October 1974*




## Electrophysiological Delineation of the Specialized A-V Conduction System in Patients with Corrected Transposition of the Great Vessels and Ventricular Septal Defect

*By* ALBERT L. WALDO, M.D., ALBERT D. PACIFICO, M.D., LIONEL M. BARGERON, JR., M.D., THOMAS N. JAMES, M.D., AND JOHN W. KIRKLIN, M.D.

*Circulation, Volume 52, September 1975*

## Intraoperative Identification of the Conduction System in Repair of Endocardial Cushion Defect

Grace S. Wolff, M.D., and Ralph D. Alley, M.D.

The Annals of Thoracic Surgery Vol 23 No 1 January 1977

encompass the usual location of the bundle. An anatomical sketch made at the operating table allowed for efficient correspondence between the surgeon and the physician viewing the oscilloscope. Variations in the anatomy of ECD de-

# Why did we stop intraoperative mapping?

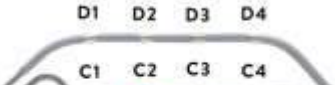
- Improved knowledge of conduction anatomy
- Improved pacemaker technology
- Changes in surgical approach

# Why start intraoperative mapping again?

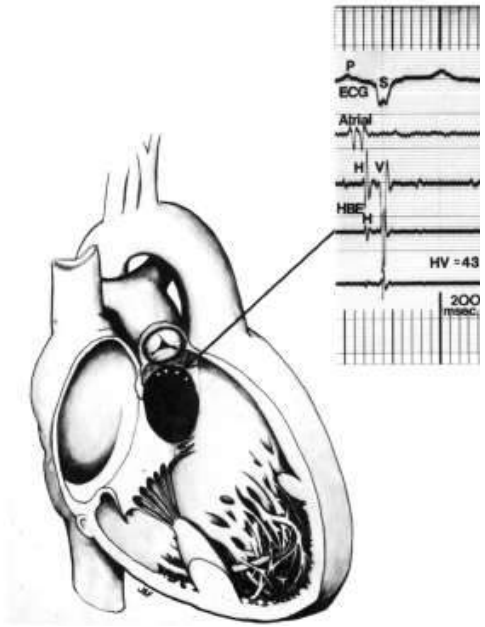

CIRCULATION VOL 59, NO 1, JANUARY 1979

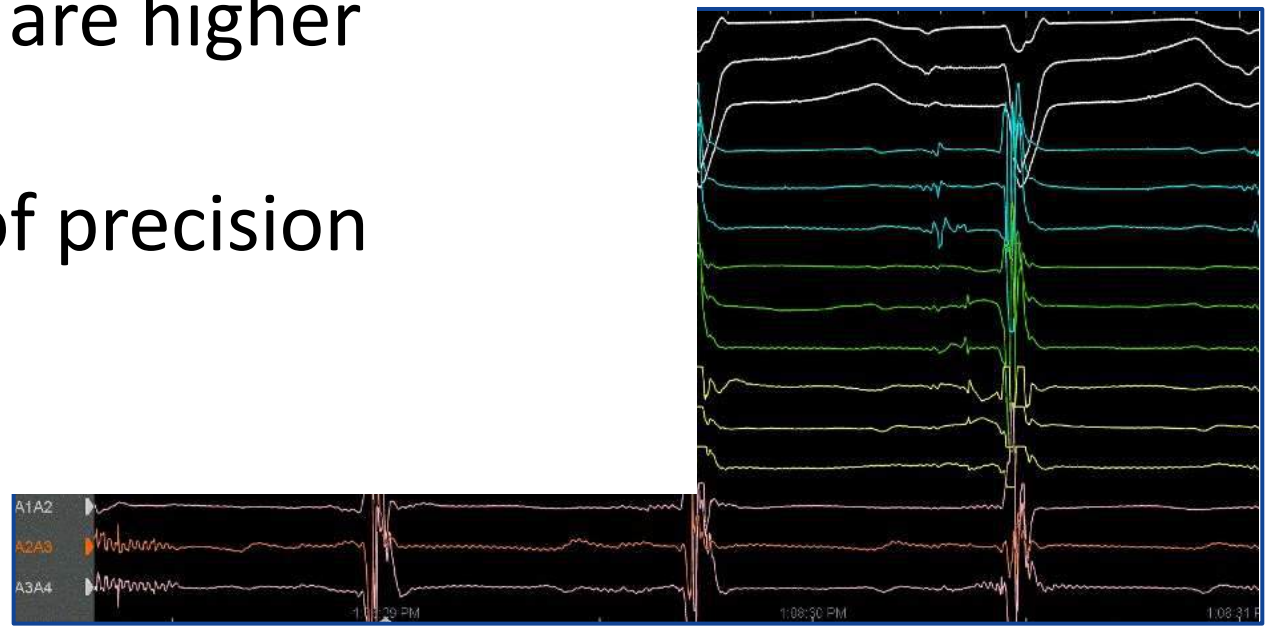
**Intraoperative Recording of Specialized Atrioventricular Conduction Tissu... in 47 Patients**

MACDONALD DICK, II, M.D., WILLIAM I. NORWOOD, M... AND ALDO R. CASTANEDA, M.D.



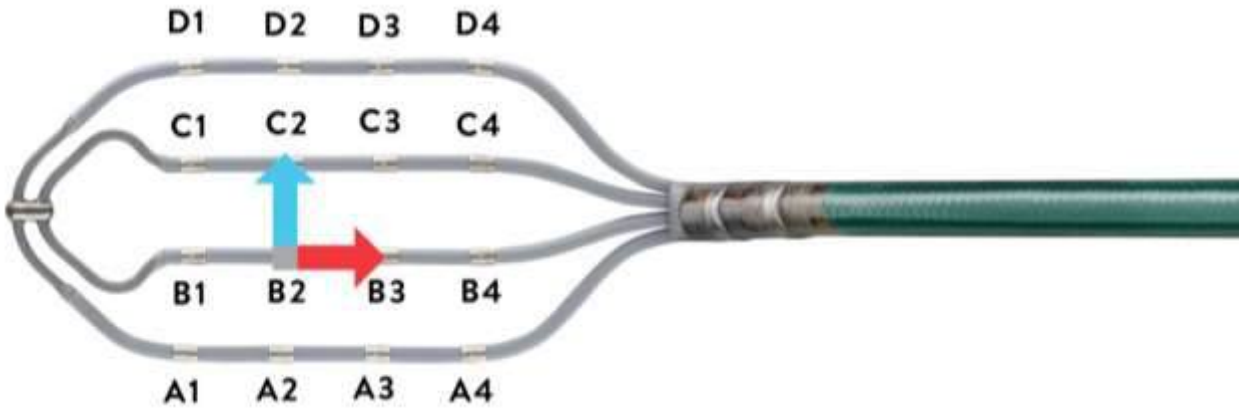

- Standard of care has shifted
- Expectations are higher
- A new level of precision medicine



# Data Acquisition

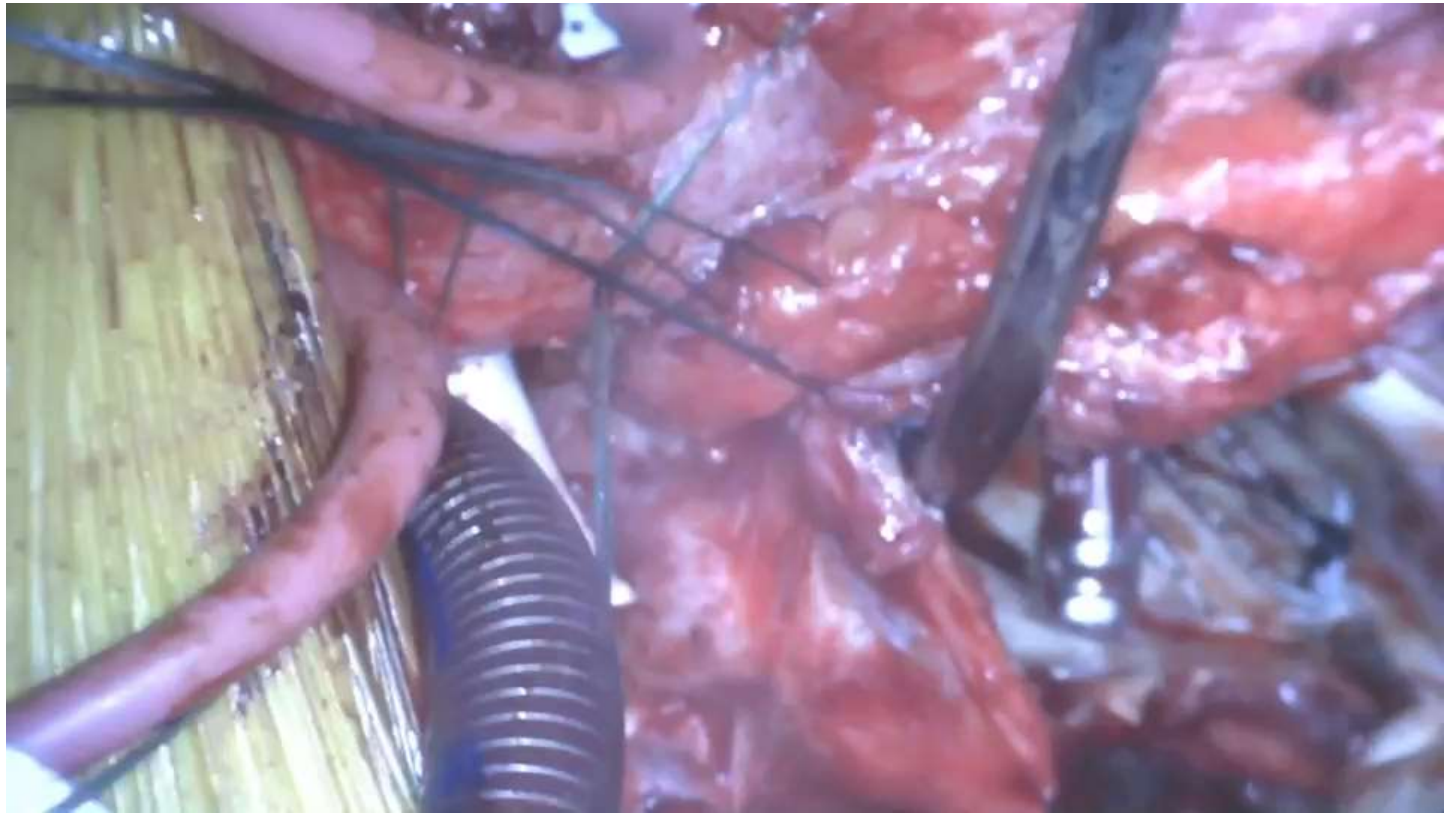
Abbott Advisor HD Grid




EP Tracer ProCart

# EP Mapping Workflow

1. Cannulation and go on CPB
2. Fibrillate
3. Atriotomy/ventriculotomy
4. Suckers across AV valves
5. Defibrillate back to NSR
    - Maintain temp ~32C
6. Map
7. Deliver cardioplegia, arrest heart, continue with surgery

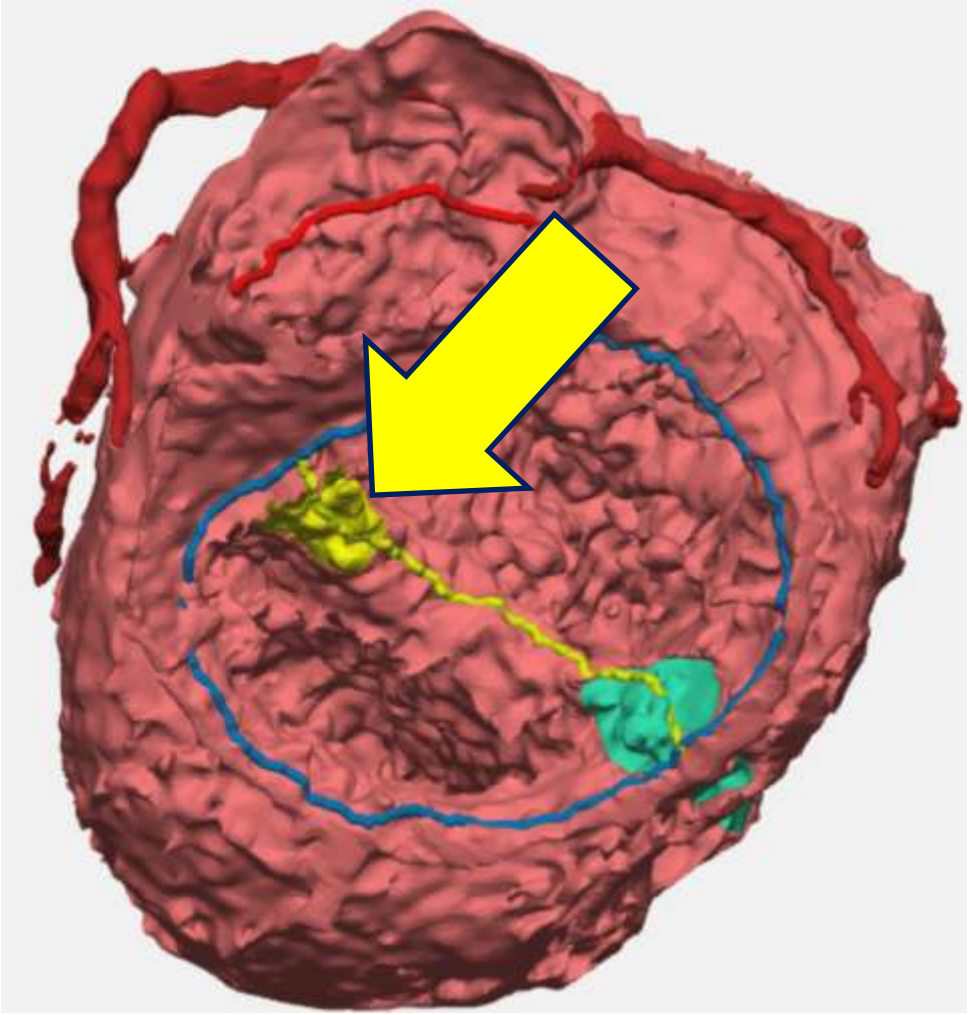


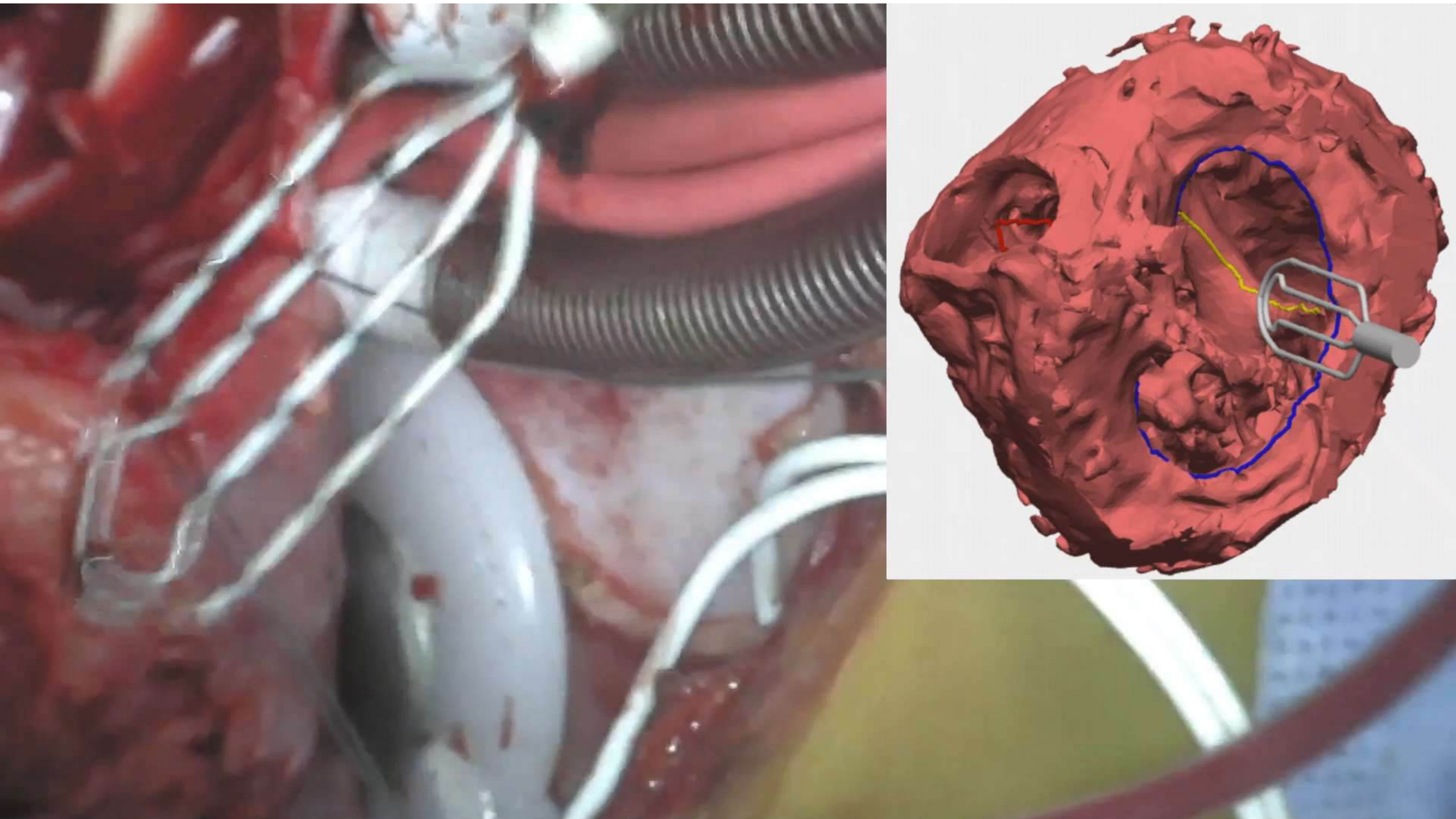

STERIS
Clear-Cuff

# Case Example

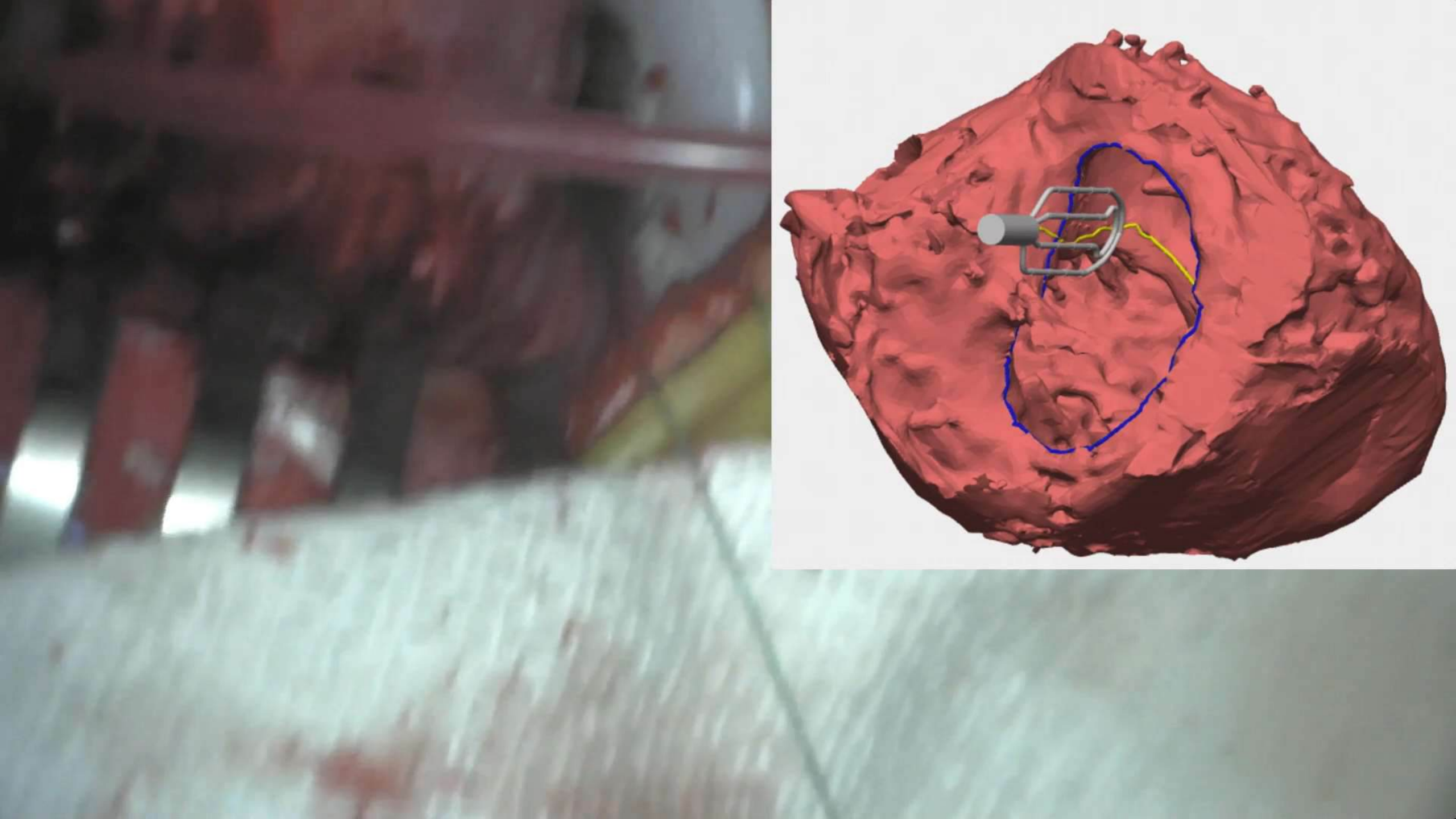
Heterotaxy/ asplenia subtype, dextrocardia, {A,L,L}, complete atrioventricular canal, double-outlet right ventricle, pulmonary atresia, and total anomalous pulmonary venous connection

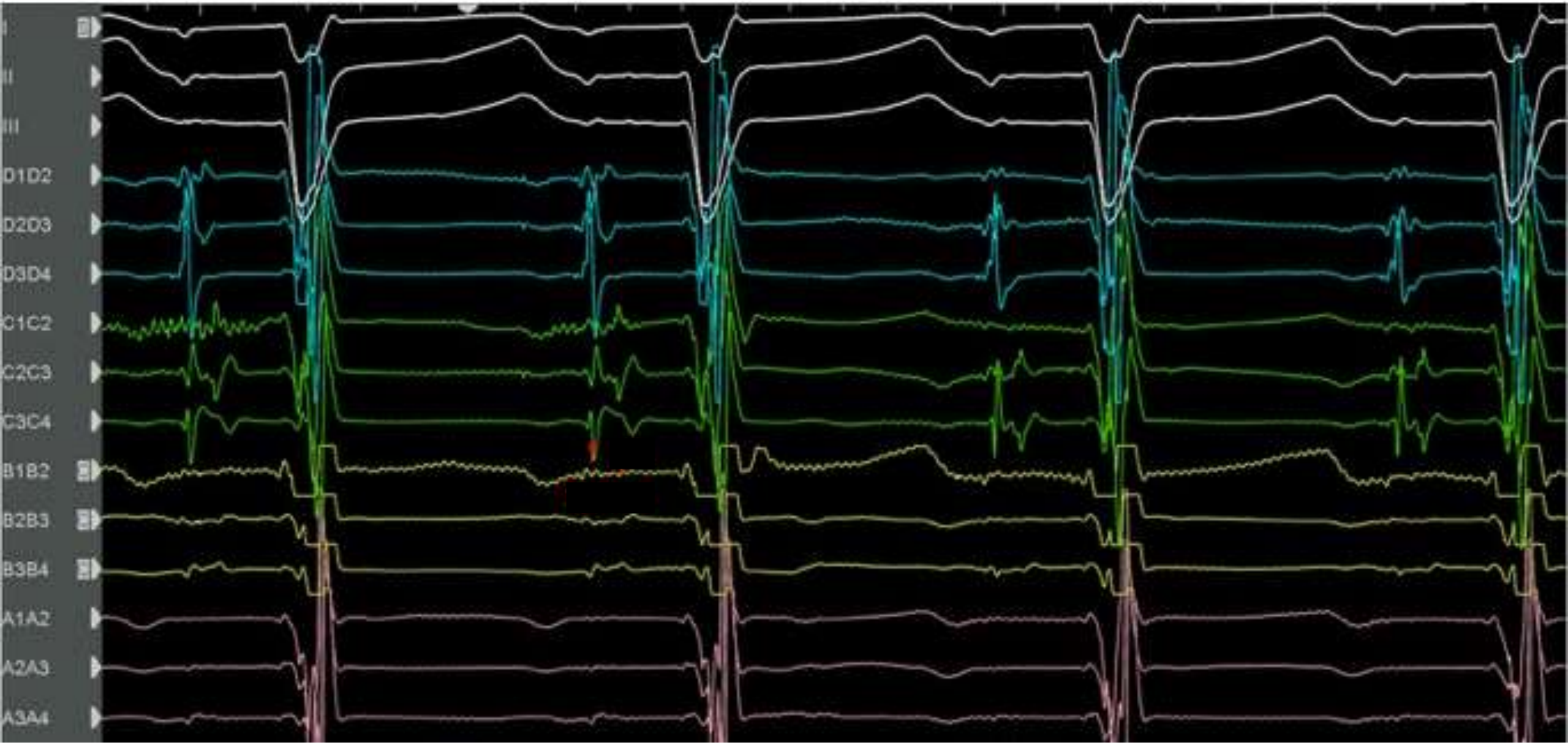
**SUPERIOR**





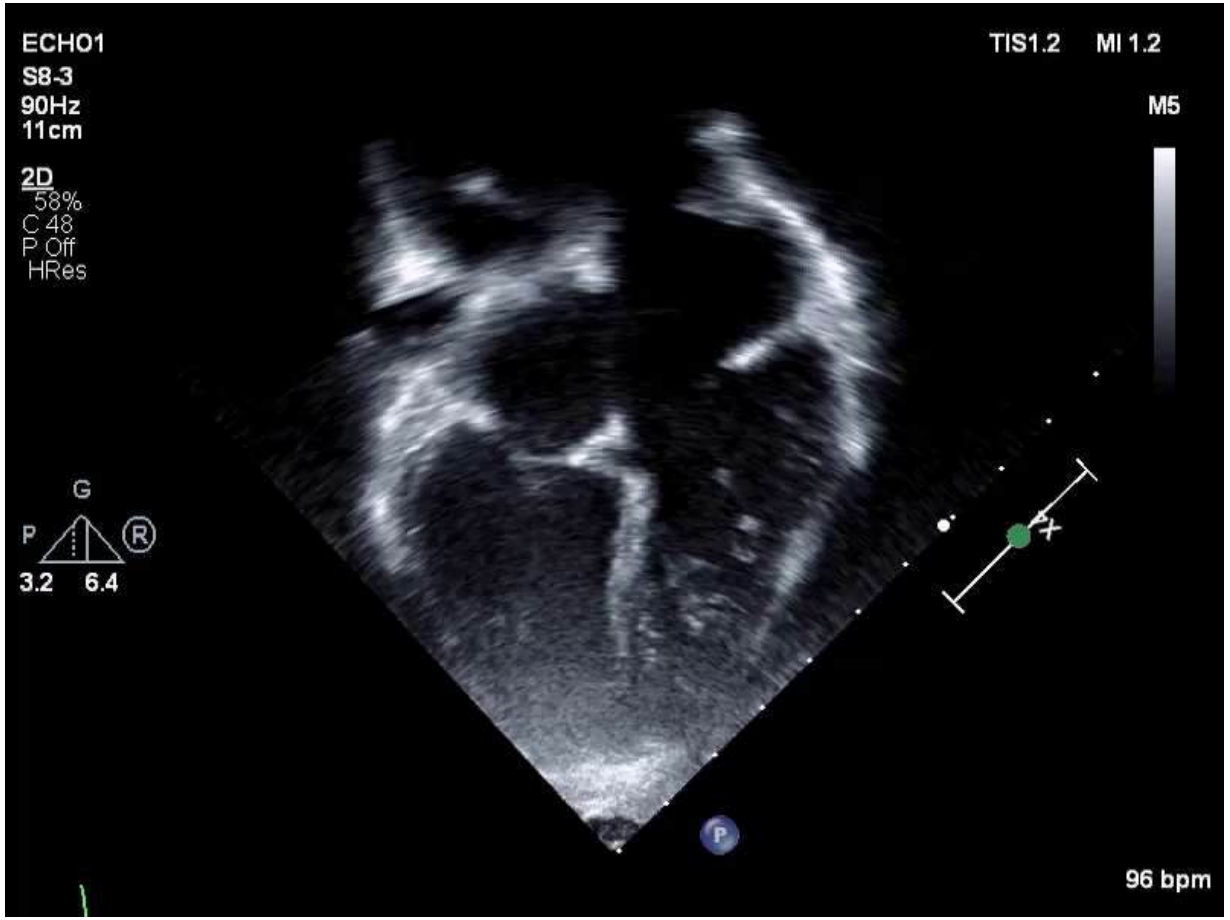

A
V
H
D1D2
D2D3
D3D4
C1C2
C2C3
C3C4
B1B2
B2B3
B3B4
A1A2
A3A4




I
II
III
D1D2
D2D3
D3D4
C1C2
C2C3
C3C4
B1B2
B2B3
B3B4
A1A2
A2A3
A3A4

# Patient Outcome

- Operative repair:
  - Atrial switch
  - take-down of bilateral BDG,
  - LV to Ao baffle with VSD enlargement
  - RV-PA conduit
- No outflow tract obstruction
- No AV block, no need for PPM

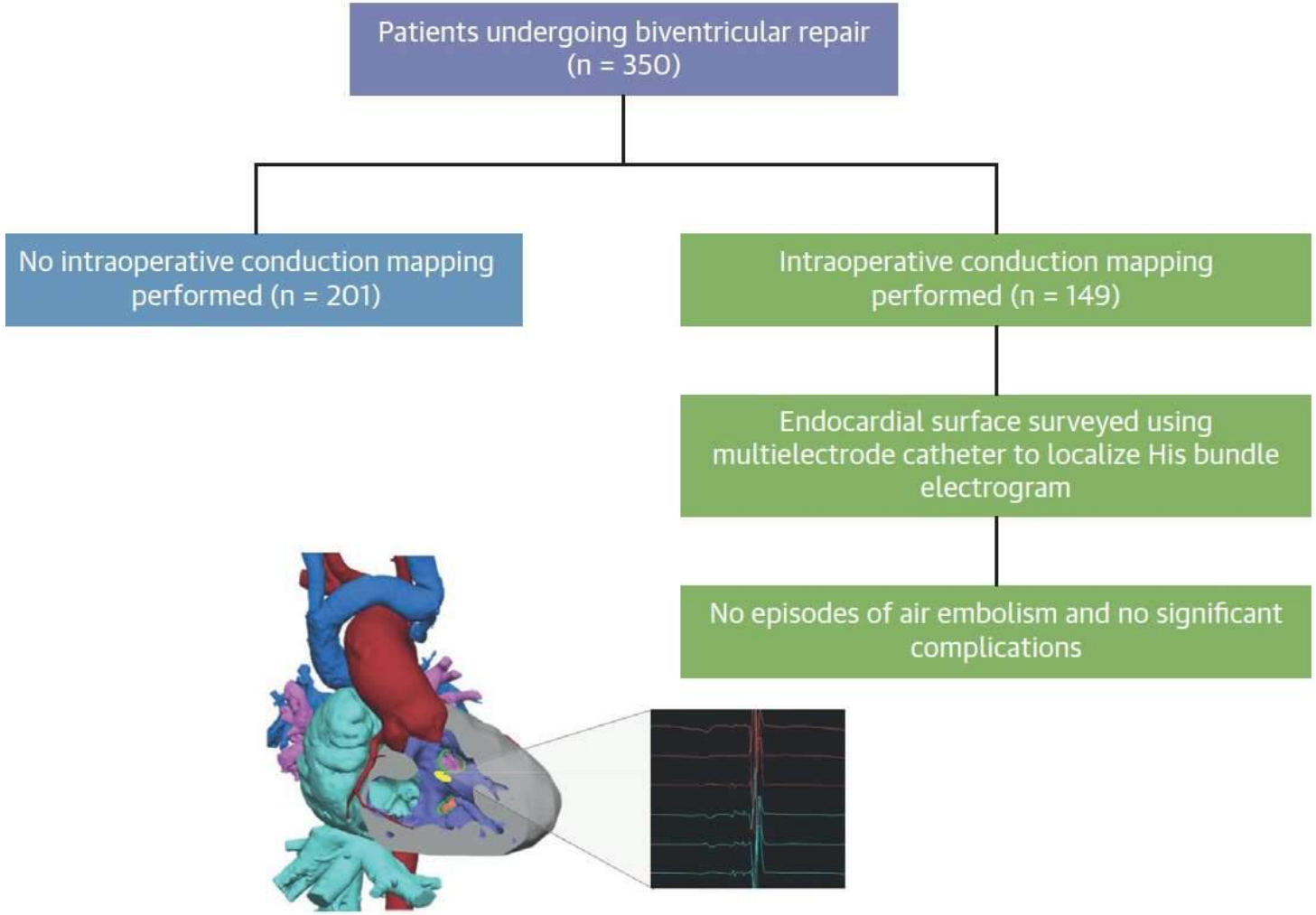


# Boston Children’s Hospital Mapping Experience

JOURNAL OF THE AMERICAN COLLEGE OF CARDIOLOGY

# Intraoperative Conduction Mapping to Reduce Postoperative Atrioventricular Block in Complex Congenital Heart Disease

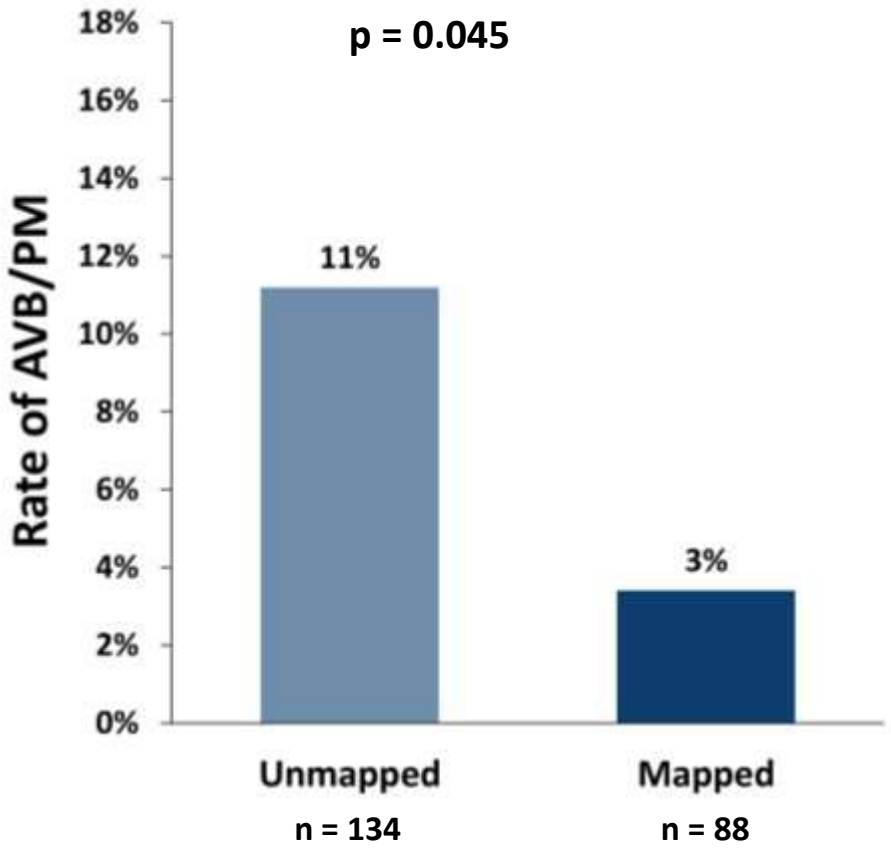
Edward T. O'Leary, MD,[a,*] Eric N. Feins, MD,[b,*] Jocelyn Davee, MS,[a] Christopher W. Baird, MD,[b] Rebecca Beroukhim, MD,[a] Pedro J. del Nido, MD,[b] Audrey Dionne, MD,[a] Kimberlee Gauvreau, ScD,[a] David M. Hoganson, MD,[b] John K. Triedman, MD,[a] Edward P. Walsh, MD,[a] Meena Nathan, MD,[b] Sitaram M. Emani, MD,[b] Elizabeth S. DeWitt, MD[a]



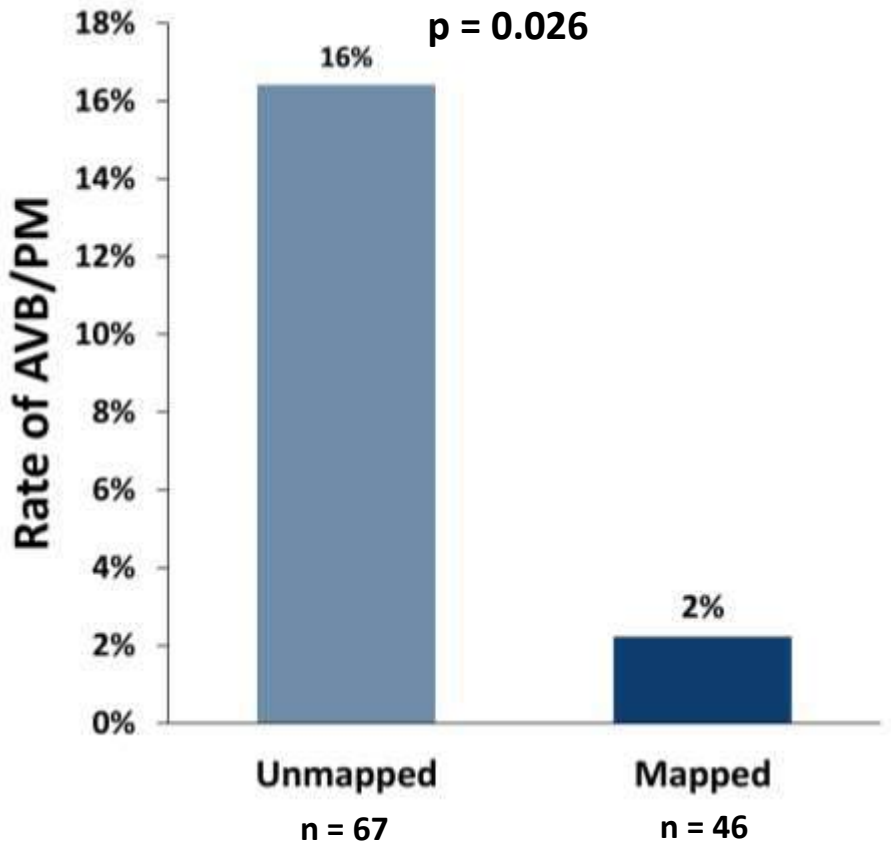

Patient-specific model demonstrating localized conduction location (yellow) near ventricular septal defects (green outlines)

# Outcomes

**Patients with Non-L Malposed Great Arteries**



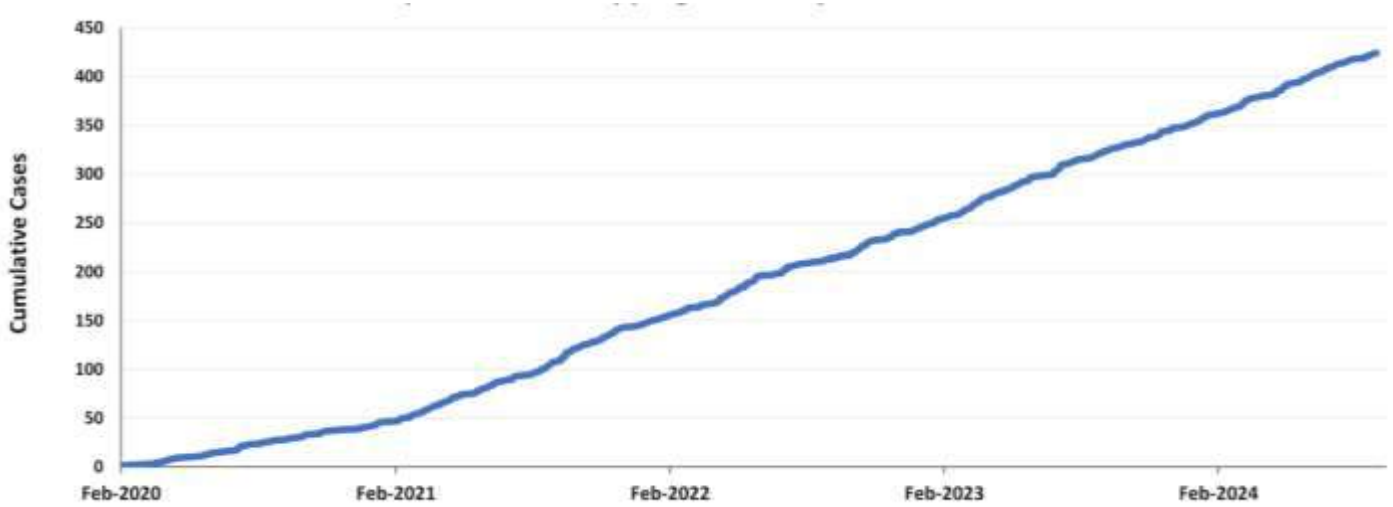

**Patients with Heterotaxy**



# Safety of Approach

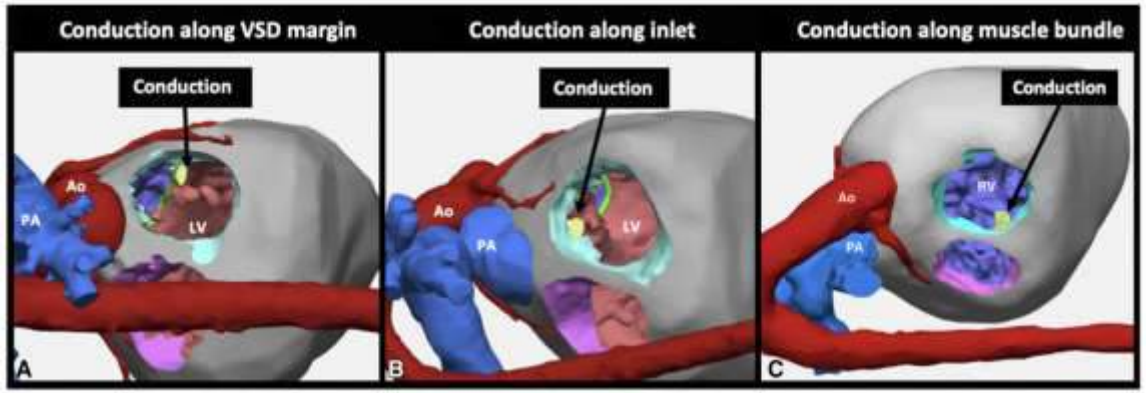
- > 450 patients have been mapped at BCH
  - No clinically identified air embolus
  - Minimal additional bypass time for mapping
  - No significant risk of mapping-induced heart block or other procedural complications

Cumulative Intraoperative Mapping Volume, BCH



# Ventricular septation for double inlet ventricle: Avoiding conduction injury

Ajami Gikandi, BA,[a] Jocelyn Davee, MS,[a] Edward T. O'Leary, MD,[b] Elizabeth S. DeWitt, MD,[b] Sunil J. Ghelani, MD,[b] Rebecca S. Beroukhim, MD,[b] Edward P. Walsh, MD,[b] Pedro J. del Nido, MD,[a] Eric N. Feins, MD,[a] and Sitaram M. Emani, MD[a]

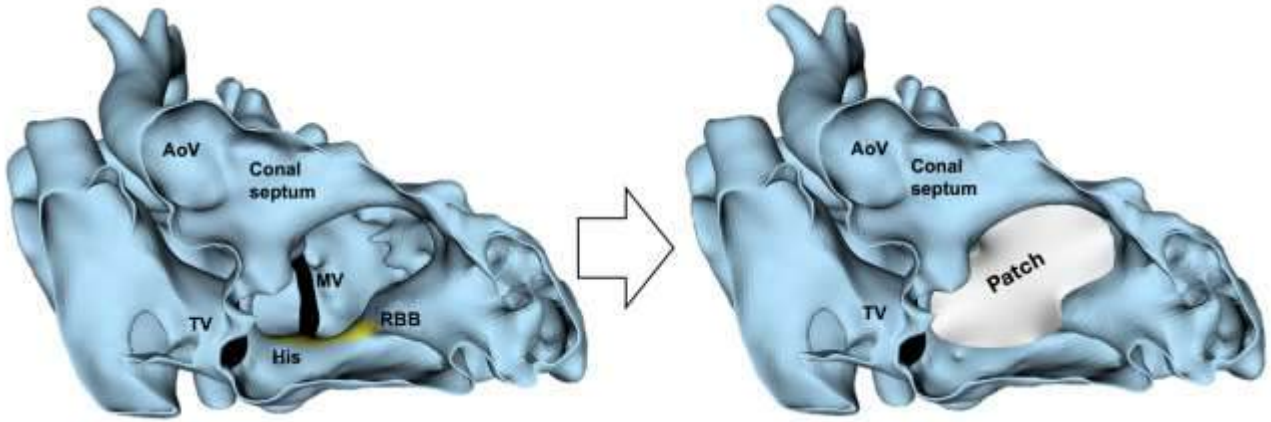



JACC: CLINICAL ELECTROPHYSIOLOGY
PUBLISHED BY ELSEVIER ON BEHALF OF THE AMERICAN COLLEGE OF CARDIOLOGY FOUNDATION
VOL. 10, NO. 8, 2024

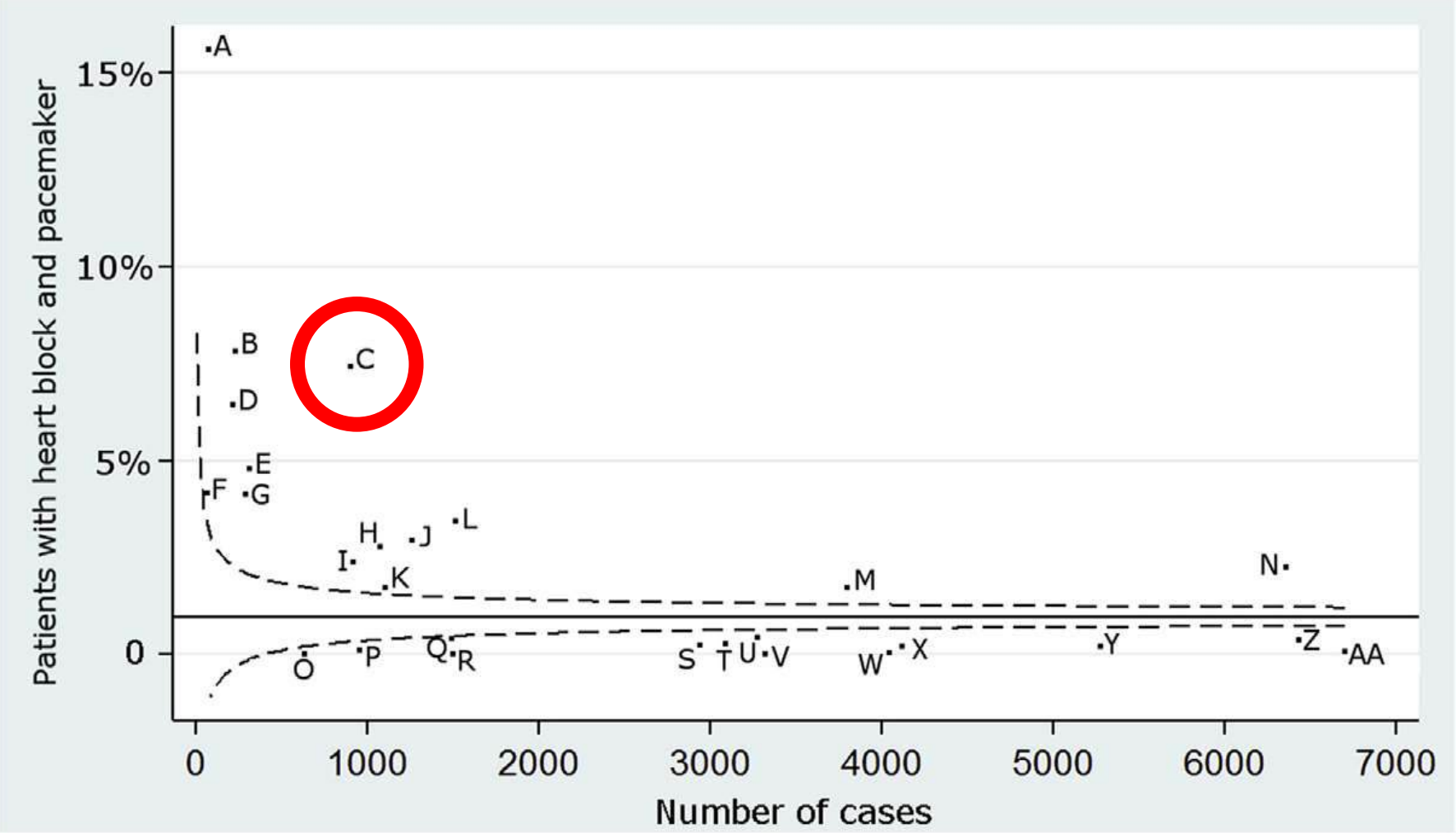
IMAGES AND VIGNETTES IN CLINICAL ELECTROPHYSIOLOGY

# Direct Intraoperative Conduction System Mapping for Cardiac Septation in Congenital Heart Disease

Jeremy P. Moore, MD, MS,[a,b] Kalyanam Shivkumar, MD, PhD,[a] Gregory Perens, MD,[b] Glen Van Arsdell, MD[c]



# Pediatric Mitral Valve Replacement

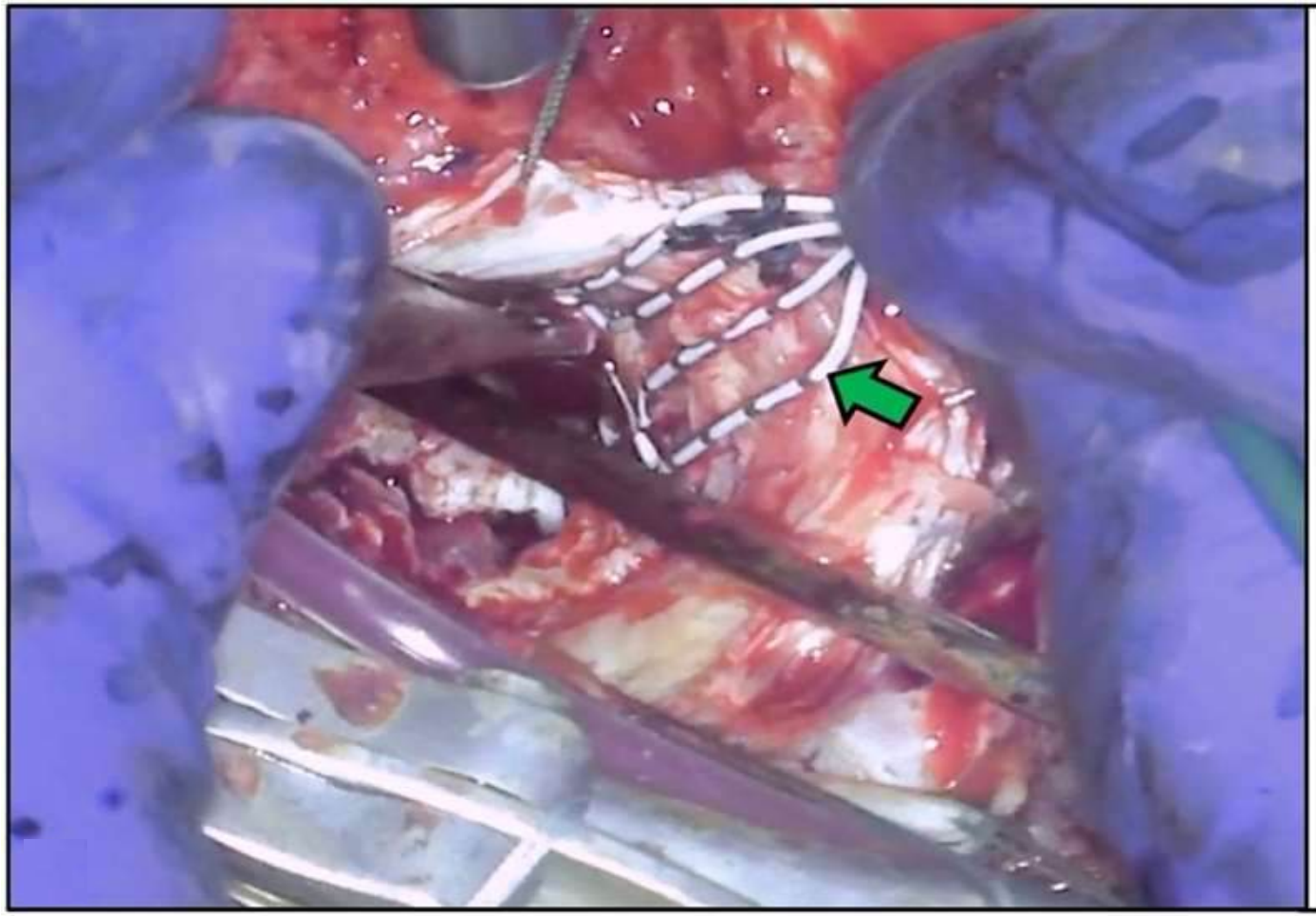


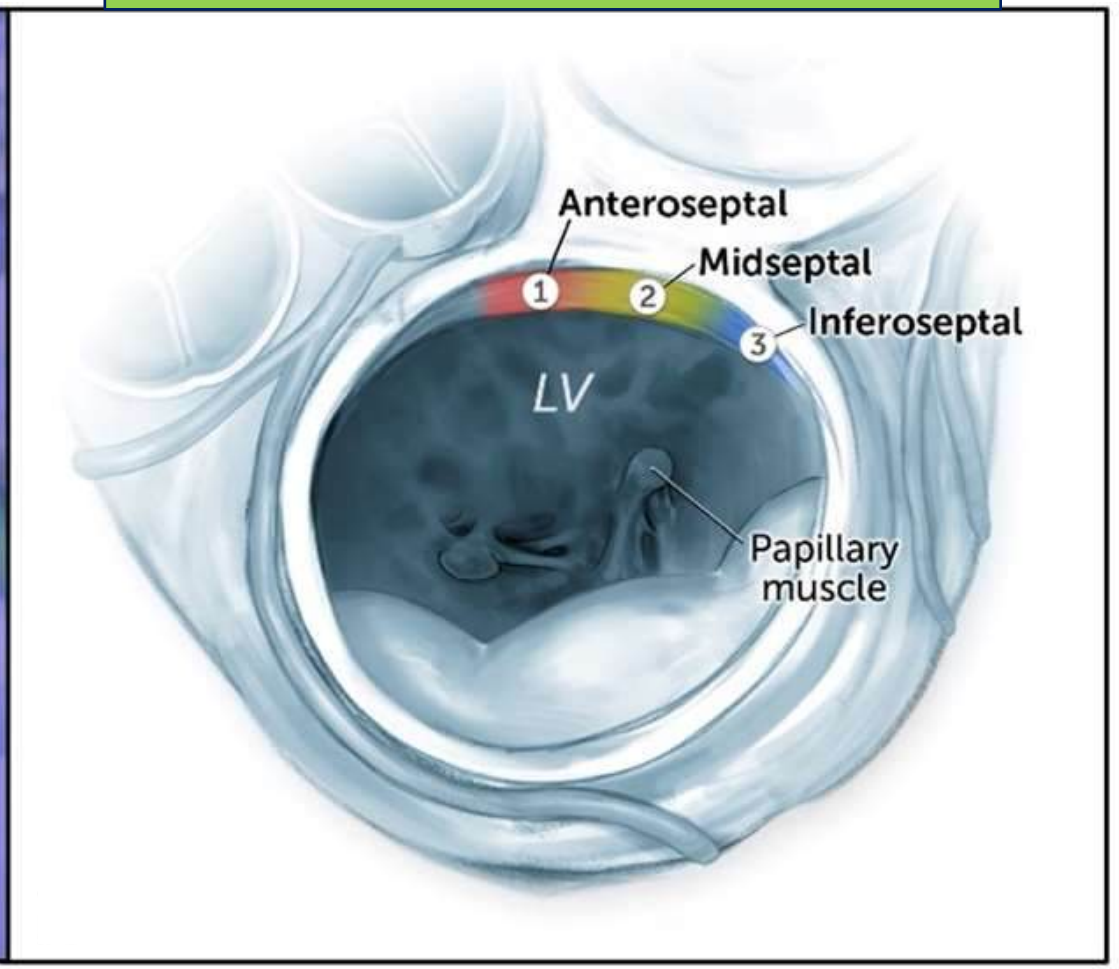

A Double Switch
B TVR
C MVR
D Atrial switch/VSD
E Rastelli
F Ebstein < 30D
G Konno
H Sub AS
I Ross
J AVR
K Coactation/VSD
L ASO/VSD
M Mitral valvuloplasty
N CAVC
O PAPVC
P TAPVC>30d
Q Norwood/HLHS
R PDA>30D
S PV replacement
T IAA/VSD
U RV->PA conduit
V Coactation >30d
W Coactation <30d
X Glenn
Y Fontan
Z BT Shunt
AA Secundum ASD

Lieberman et al, JTCVS 2016 152:197-202

# Mapping at Mitral Valve Replacement

**His Bundle Location**

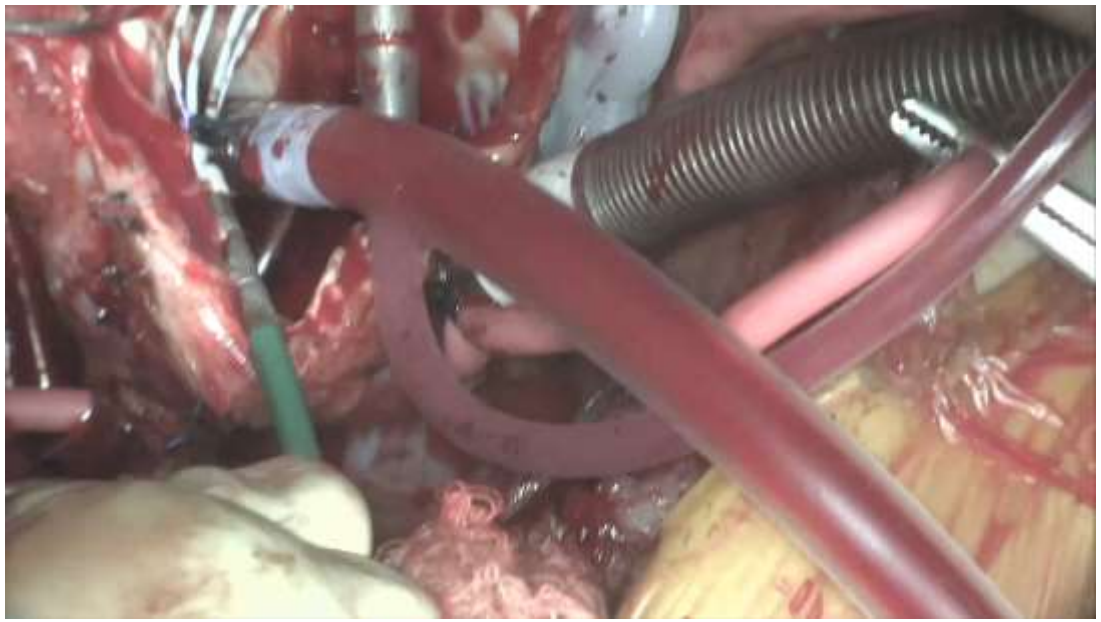


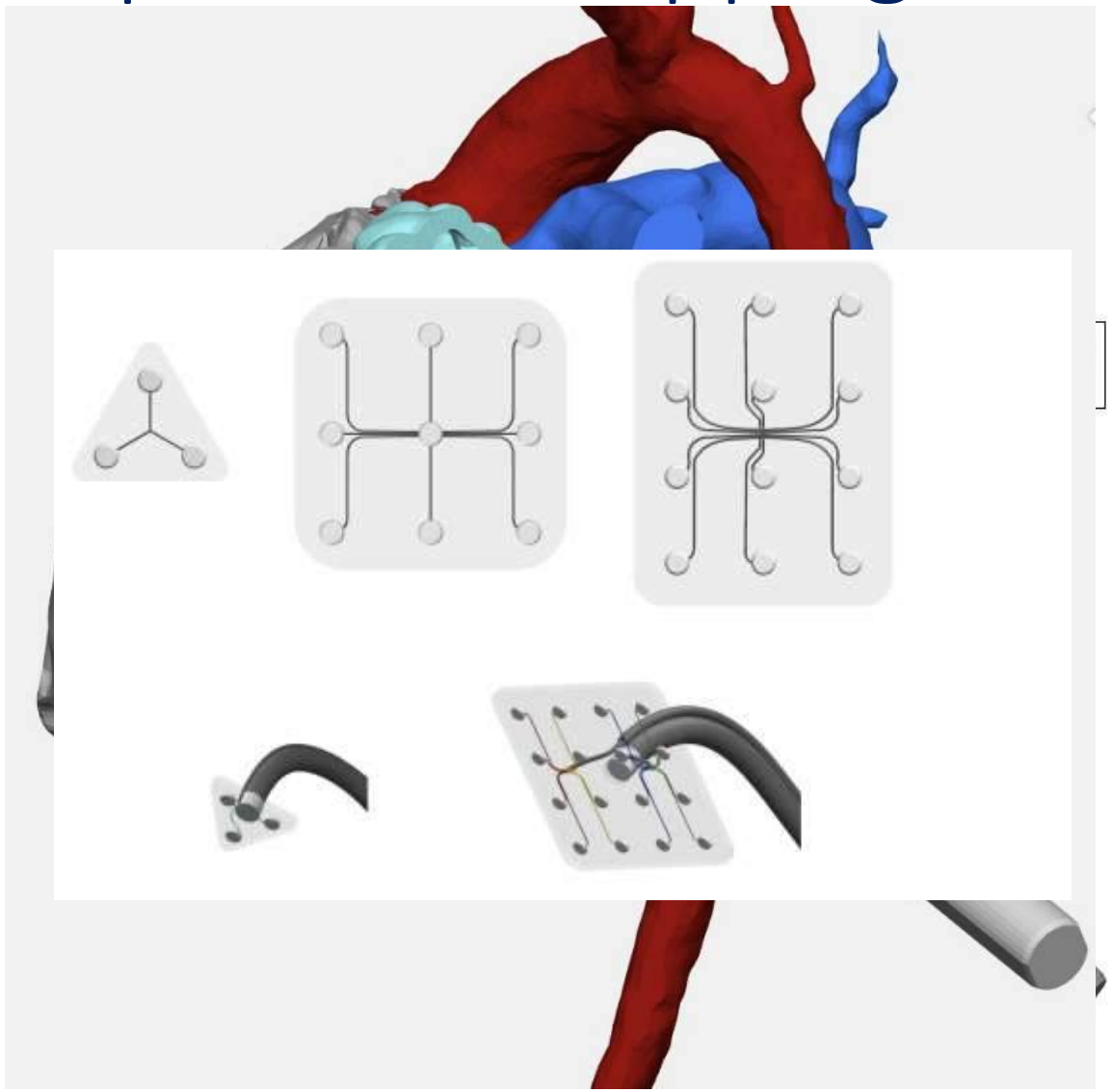


# Technical Challenges to Mapping

- Equipment available
  - No commercially available device for this application
  - Need for a mobile EP recording system
- Patient size and exposure
  - Catheter size relative to the heart
  - Movement noise
  - Reach to the heart via atriotomy, ventriculotomy

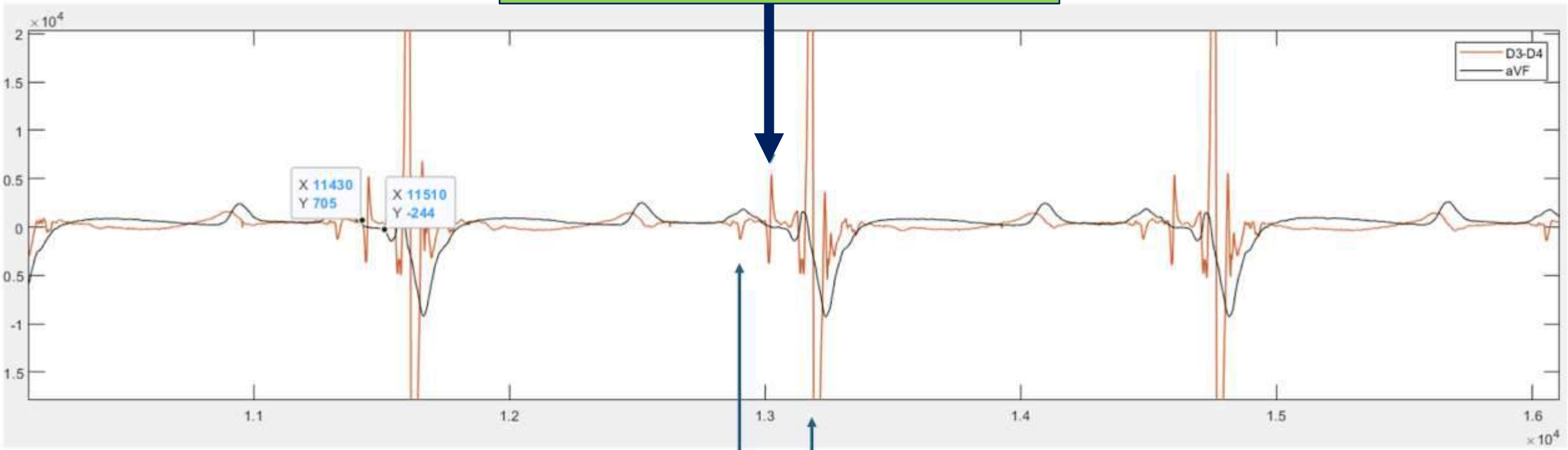
# Improving Tools for Intraoperative Mapping





# Machine Learning - *Automated Signal Recognition*

**His Bundle Electrogram**

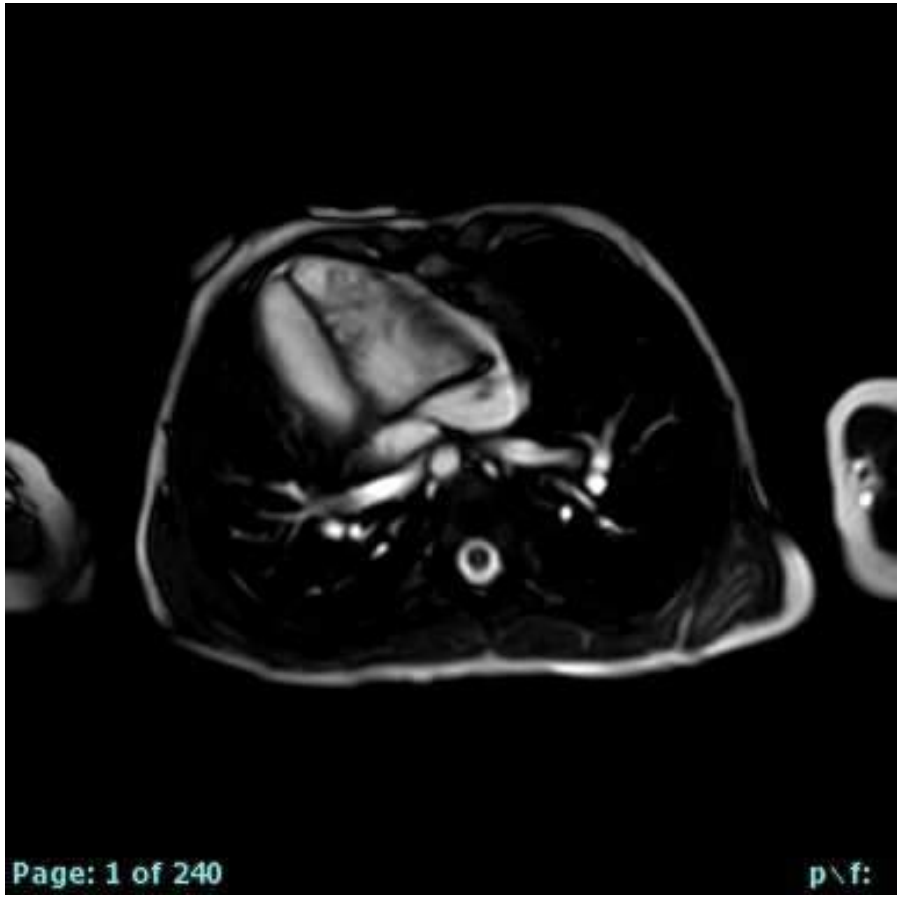



**P wave**
***atrial signal***

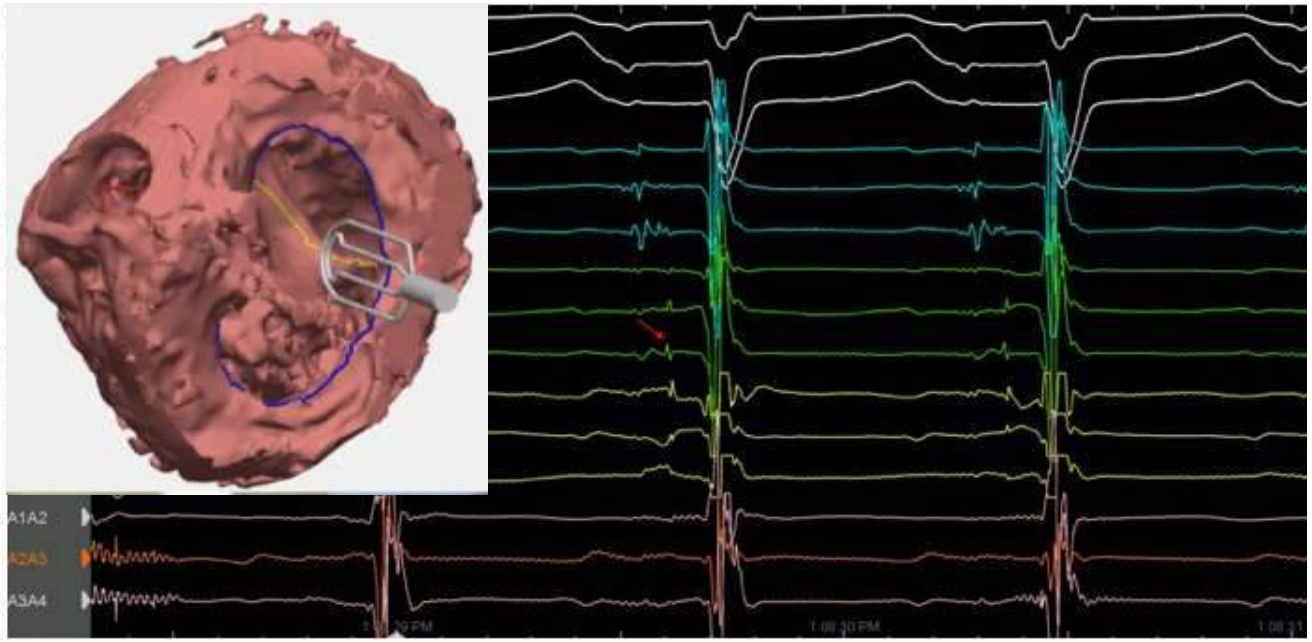
**QRS complex**
***ventricular signal***

# Should conduction localization be standard of care?

## Structural Evaluation




## Functional/EP Evaluation



# Conclusions

- Mapping → “precision medicine”
- Enhanced surgical planning → reduced operative morbidity / mortality
- Ongoing innovation → improved accuracy & ease of mapping
- Multidisciplinary collaboration is critical

# Our Team

Elizabeth DeWitt, MD
Cardiac Electrophysiology

Eric Feins, MD
Cardiac Surgery

Edward O'Leary, MD
Cardiac Electrophysiology

Jocelyn Davee, MS
Cardiac Engineering/
Surgical EP

- Pedro del Nido, MD; Christopher Baird, MD and Sitaram Emani, MD (Cardiac Surgery), Ed Walsh MD; John Triedman, MD (Electrophysiology)

- Jocelyn Davee, MS; Noah Schulz, MS, ME; Emily Eickhoff, MS; David Hoganson, MD; Peter Hammer PhD (Cardiac Engineering Team)

- Funding: Boston Children's Hospital Heart Center Strategic Investment Grant, AATS Foundation Surgical Investigator Award