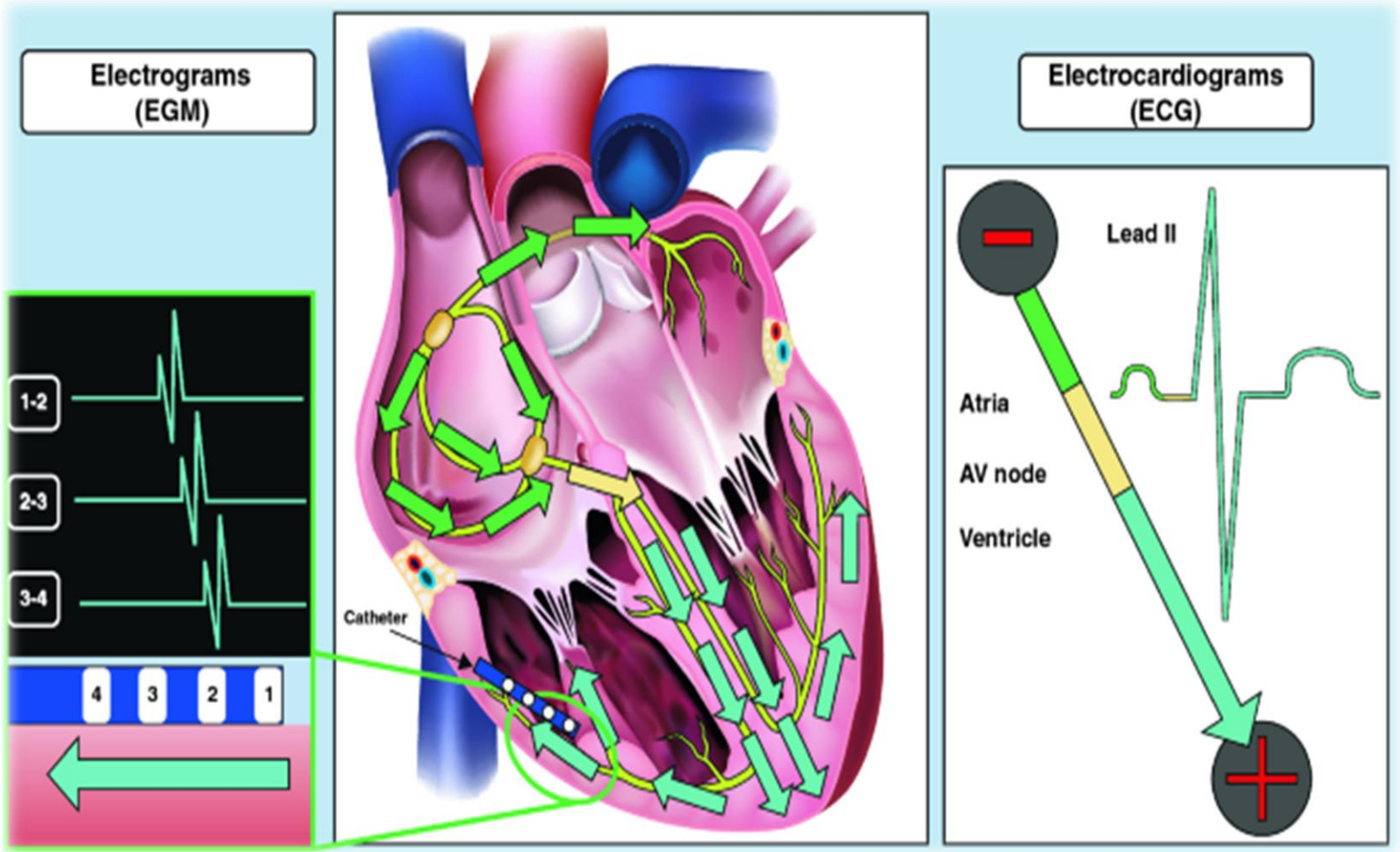
Basic in Arrhythmia and Electrophysiology

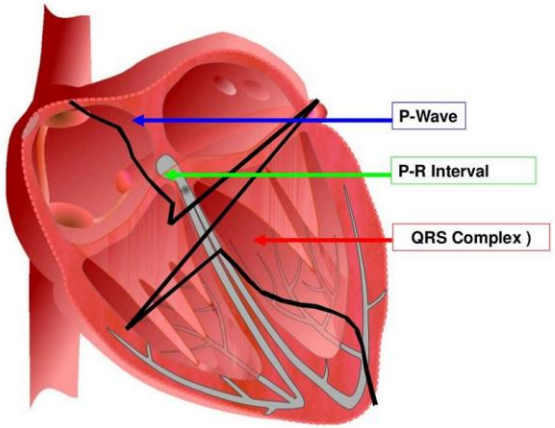
Signals and Signal Processing for Allied Professionals

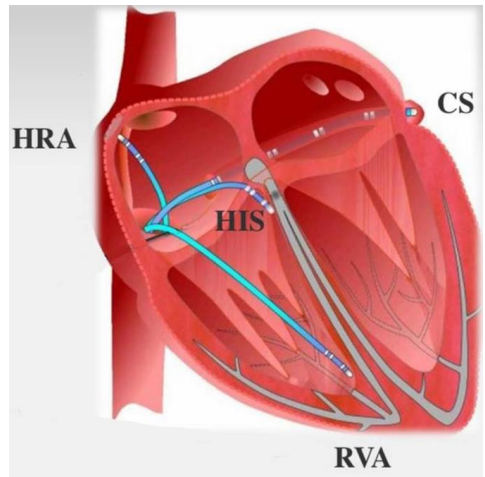
Part I : Electrogram Acquisition Part II : Signal Processing and Artifact

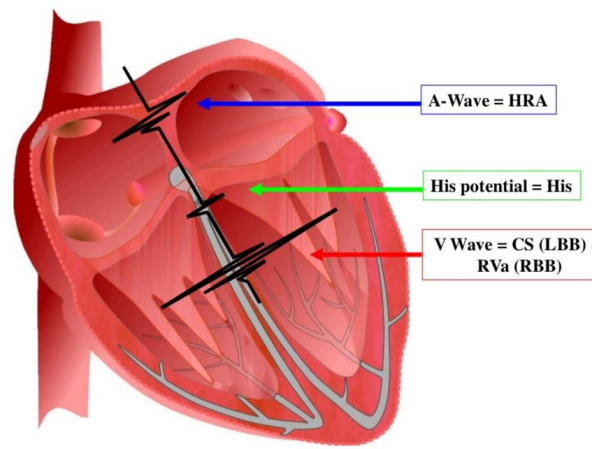
Samsung Medical Center

Lee Chang Hee MSc, CEPS, RDCS


Electrograms
(EGM)
1-2
2-3
3-4
4
3
2
1
Catheter
Electrocardiograms
(ECG)
Lead II
Atria
AV node
Ventricle


P-Wave
P-R Interval
QRS Complex)


HRA
CS
HIS
RVA


A-Wave = HRA
His potential = His
V Wave = CS (LBB)
RVa (RBB)

Approach ECG Analysis

- Step 1: Calculate rate.
- Step 2: Determine regularity.
- Step 3: Assess the P waves.
- Step 4: Determine PR interval.
- Step 5: Determine QRS duration.

(RR-P-QRS-T)

1. Rate(atrium and ventricle)
2. Rhythm
3. P & PR
4. QRS (A-MS-W, rotation)
5. ST-T

   etc. QT/QTc & U

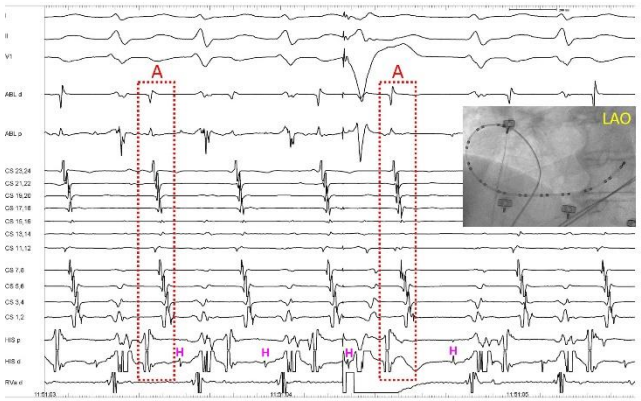
Approach EGM Analysis

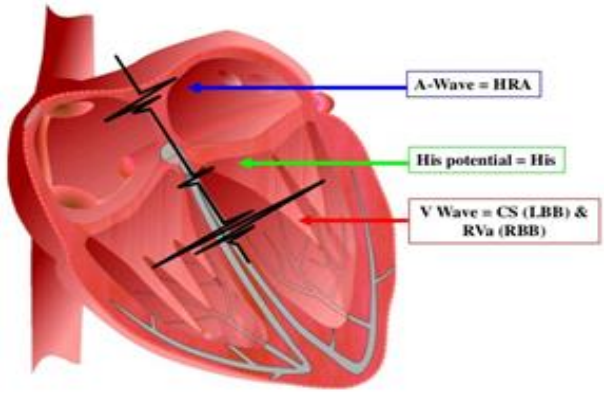
Basic rhythm

EGM morphology

Atrium, His, RV

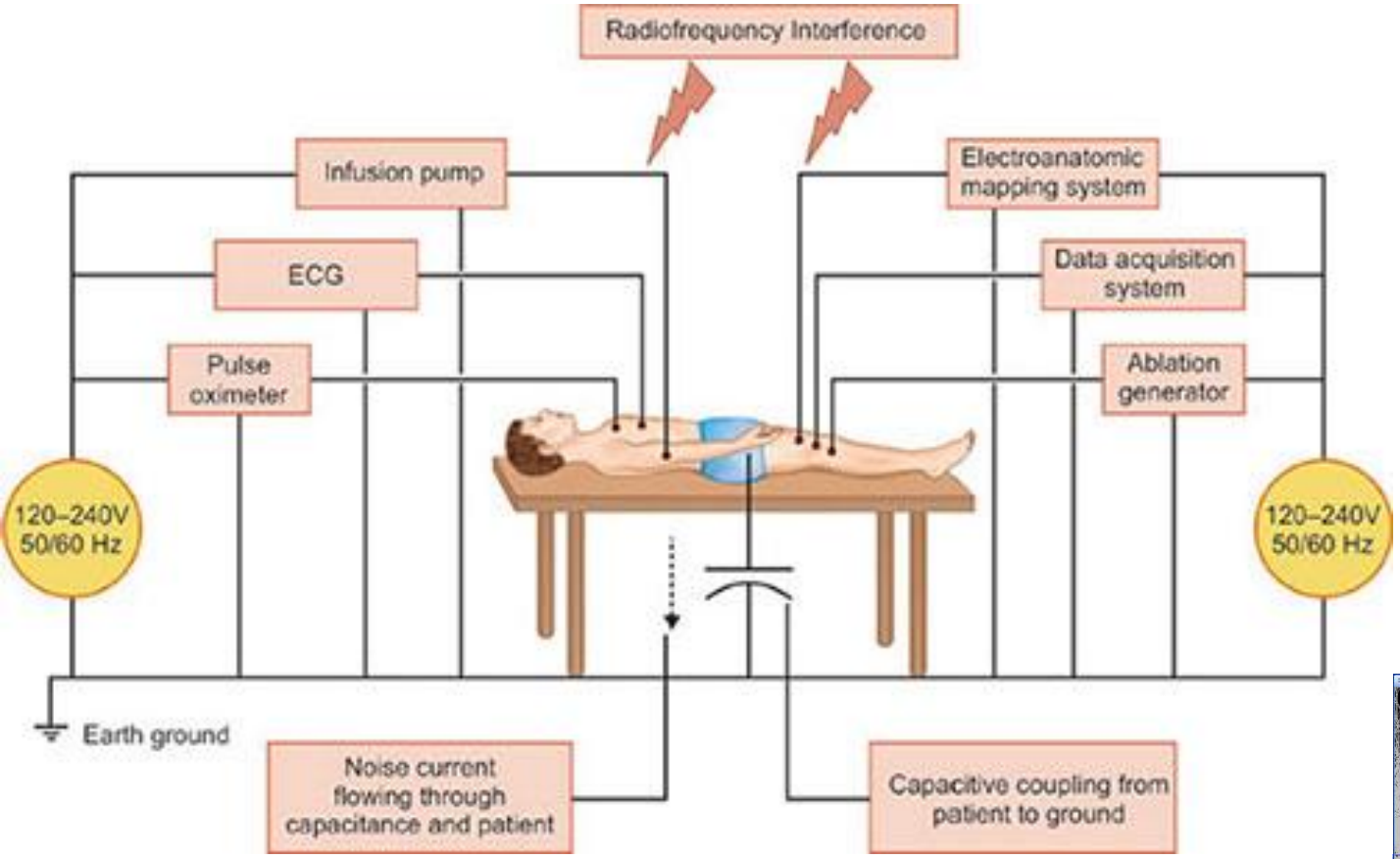
EGM sequence of activation

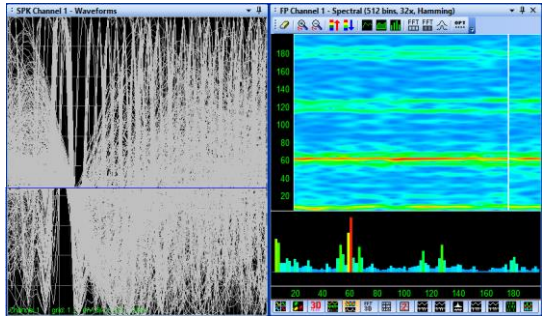




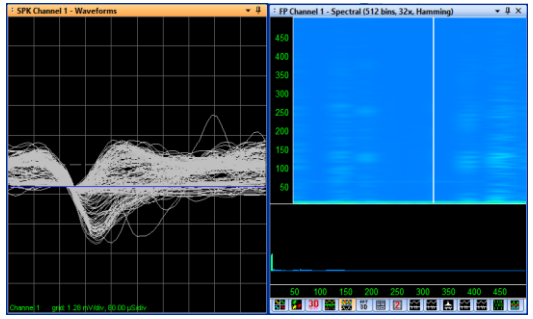
Regularity rhythm

AV relationship

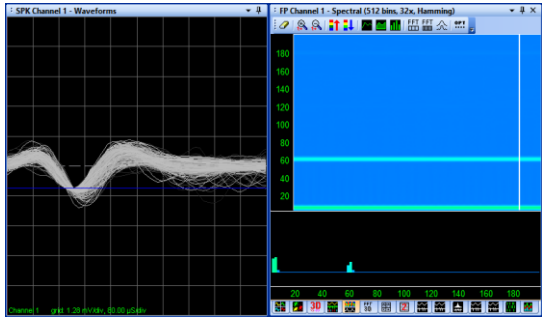




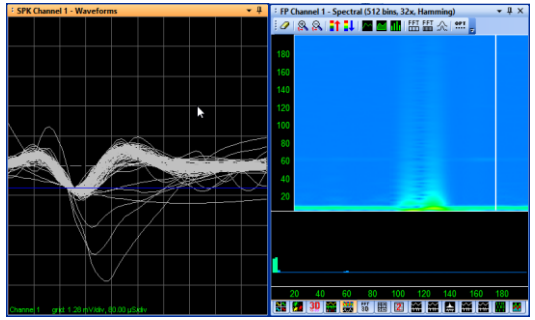
A poor ground or reference connection



wireless device communicating through WiFi

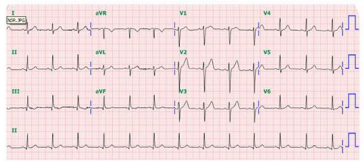


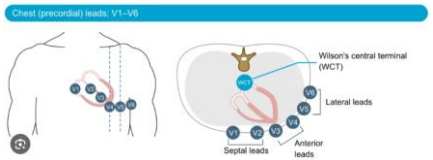
power conduit in the wall



movement artifacts

Cardiac ElectroPhysiology Laboratory





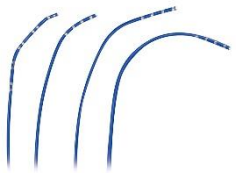
Chest and limb electrodes

ECG amplifier system

A/D Converter

To right leg electrode

From catheters



Instrumentation amplifier

Variable Gain

HPF

LPF

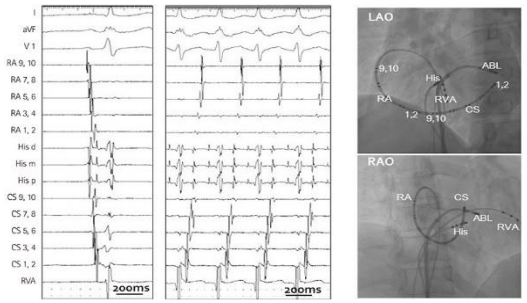
Notch

Gain

A/D Converter

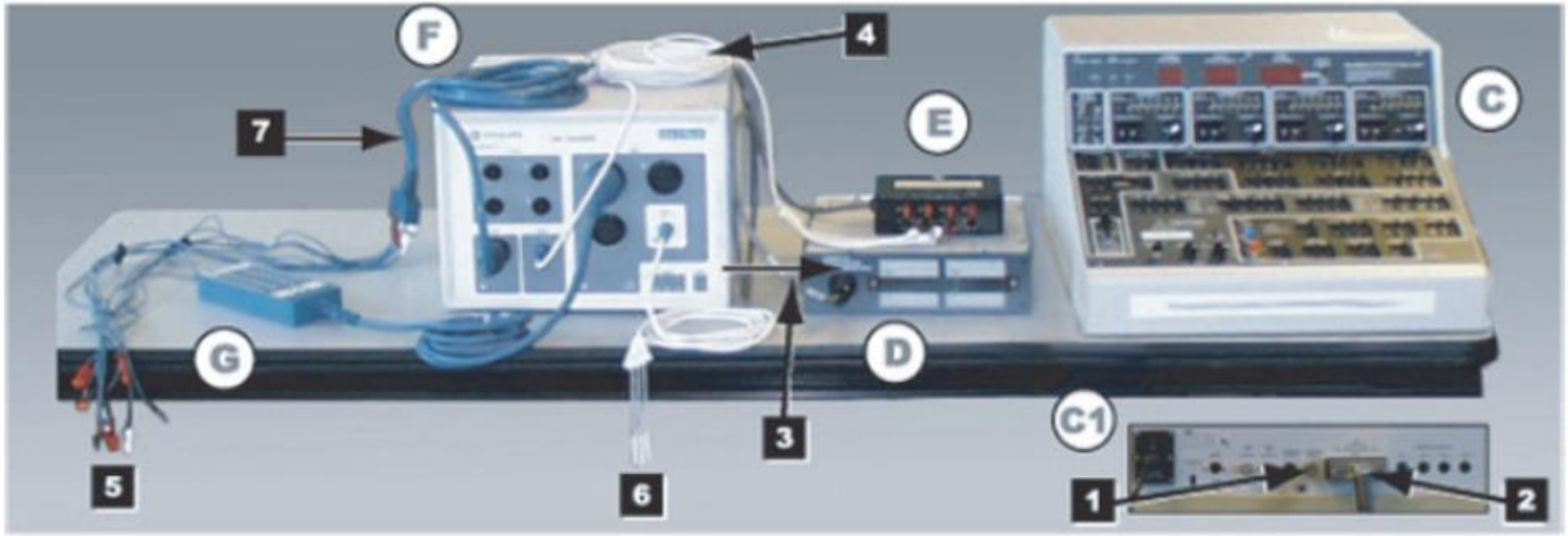
Microprocessor & Memory

64 to 128 channels

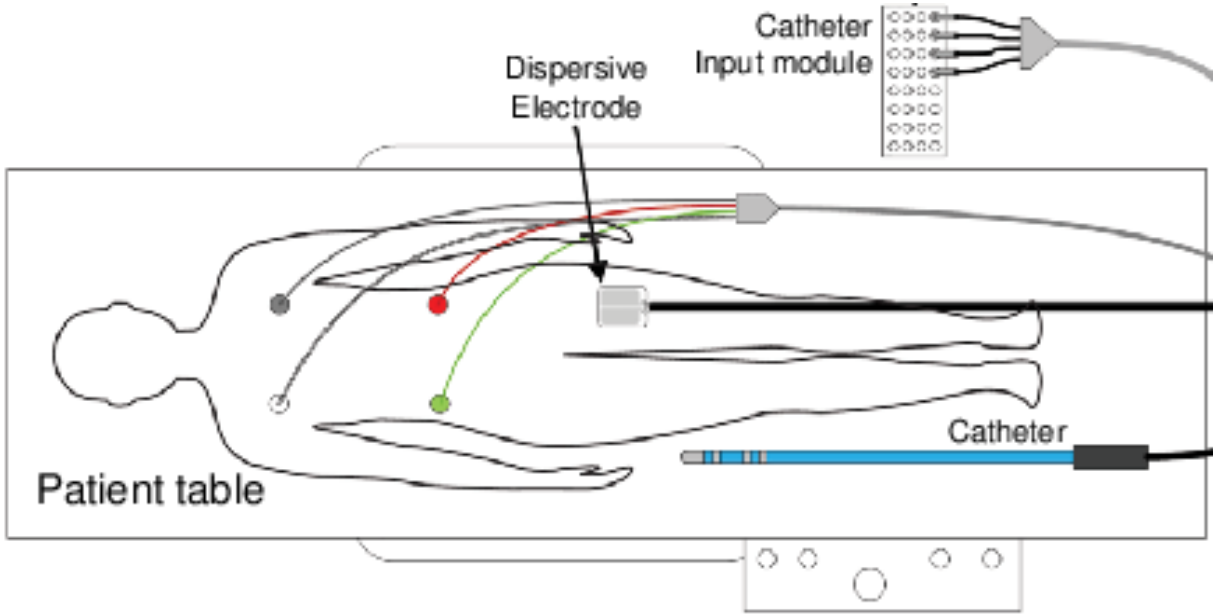


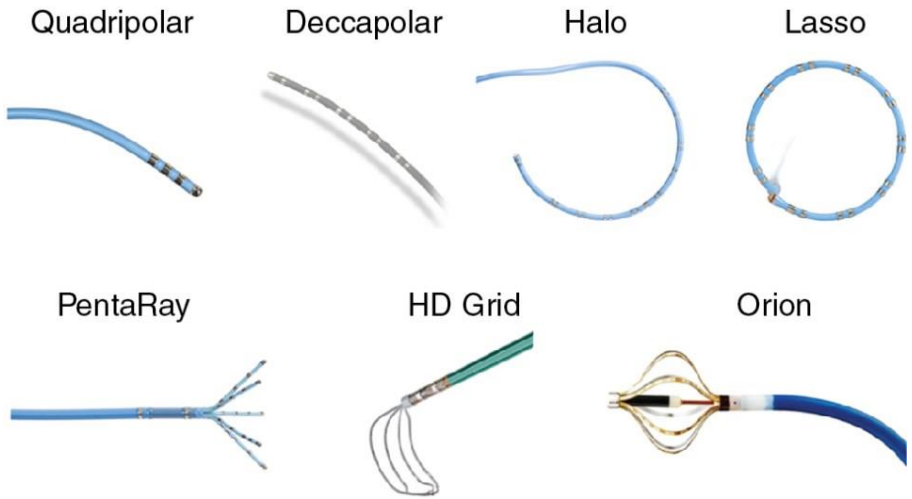
To display and printer

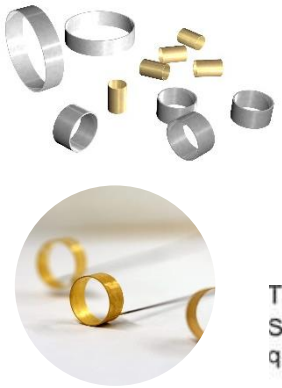
Circ Arrhythm Electrophysiol. 2011;4:965-973

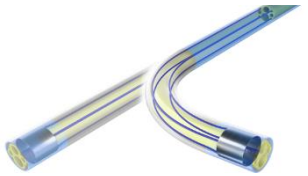


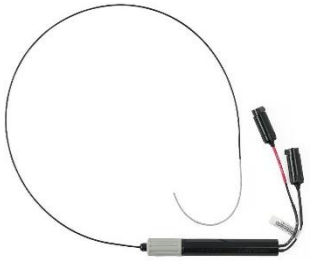
Item	Part Number	Description
C and C1	N/A	Bloom (This is a typical example. Specific equipment may vary by location). Connects to the IEB (not shown) via the External Input BNC jack on the back (C1) and the Patient Isolation Box (D) via a large cable with square connectors. (See next section for detail.)
D	N/A	Patient Isolation Box. Rear connection to Bloom (C1) via large cable with square connectors. Front connection to Catheter Connection Box (E). Front panel provides access to internal batteries.
E	N/A	Catheter Connection Box. Side connection to the Patient Isolation Box (D) front connector. Red and Black leads connect from the front to the Amplifier (F) Stim Input.
F	2003232-00X	**NOTE:** For 2003232-00X, X = 1, 2, 3, or 4. Amplifier connected to ■ (1) External ECG connection ■ (2) Catheter Input Module ■ (3) Auxiliary Reference Cable ■ (4) Catheter Connection Box
G	301-00202-08	Catheter Input Module. Catheter leads (not shown) plug into the block end. Connector on other end plugs into the Amplifier (4) Cardiac Input (Labeled A, B, C and so on).

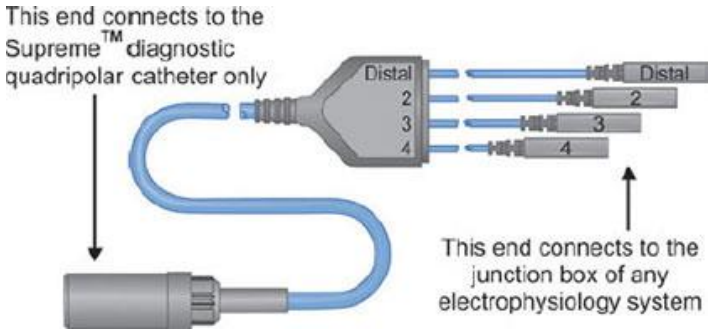

Catheter
Input module
Dispersive
Electrode
Catheter
Patient table

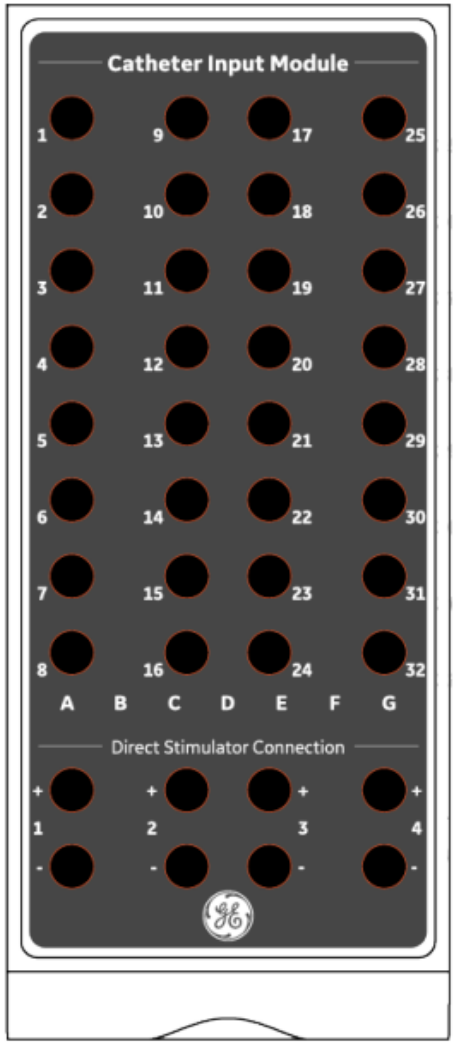

Quadripolar
Deccapolar
Halo
Lasso
PentaRay
HD Grid
Orion

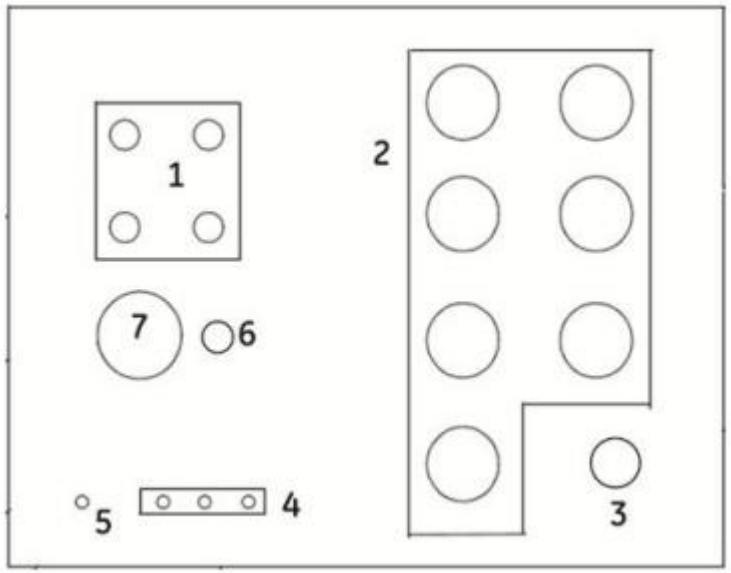




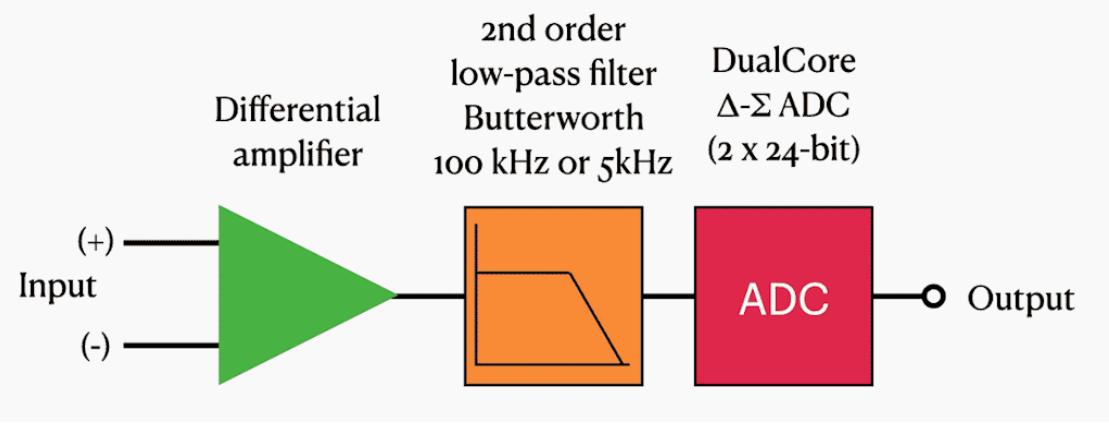


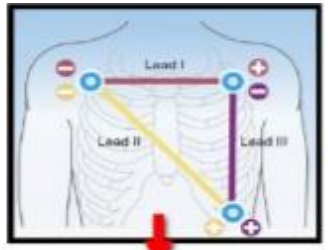

This end connects to the
Supreme™ diagnostic
quadripolar catheter only
Distal
2
3
4
This end connects to the
junction box of any
electrophysiology system


Catheter Input Module
1 9 17 25
2 10 18 26
3 11 19 27
4 12 20 28
5 13 21 29
6 14 22 30
7 15 23 31
8 16 24 32
A B C D E F G
Direct Stimulator Connection
+ + + +
1 2 3 4
- - - -



항목	증폭기 구성품	설명
1	침습 혈압 입력	혈압 입력 케이블 및 혈압 트랜스듀서에 대한 연결입니다. **중요 사항** 혈압 트랜스듀서는 감도가 5uV/V/mmHg여야 합니다.
2	심장내 ECG 입력	카테터 입력 모듈 및 카테터에 대한 연결입니다.
3	보조 입력	보조 입력 케이블 및 카테터에 대한 연결입니다.
4	통신 표시기	정비 및 문제 해결용입니다.
5	전원 표시등	녹색이면 증폭기에 전력이 공급되고 있음을 의미합니다.
6	자극 입력	자극기 입력 케이블에 대한 연결입니다.
7	ECG 입력	ECG 입력 케이블 및 ECG 리드선에 대한 연결입니다.





The leads record the raw electrical potential data and send it to the amplifier.

Amplifier

The Amplifier increases the amplitude of the signals (often up to a factor of 10000).

High Pass Filter

The high-pass filter removes any base line drift or physiologic noise by cutting off anything below a set value.

Isolation Amplifier

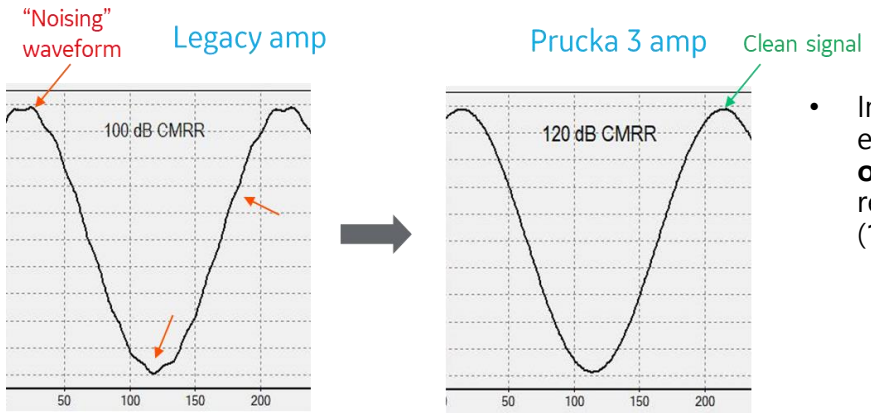
An isolation amplifier isolates the circuit from the patient (this can be done by transmitting the signals optically).

Low Pass Filter

The low-pass filter removes any environmental noise by cutting off anything above a certain value.

The resultant signal is either the surface EKG or intracardiac signals of interest.

• Reduce environmental noise by 10X



- Improved proprietary el ectronics = **high comm on mode** rejection ratio (120 dB)

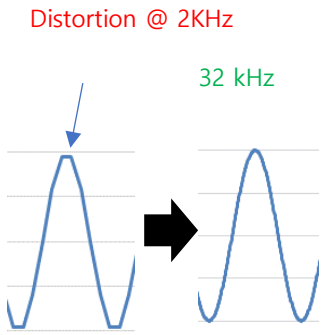
• Resolve the tiniest signal

- Low system noise due to advanced digital technology
- **1uV** typical baseline noise
- **4uV** typical smallest resolvable signal

High signal fidelity at all acquisition modes

- All signals are handled identically with **high precision** components to minimize noise in every signal combination
- Unipolar, ablate-record, pace-recording etc.

Your Next Gen EP platform



- **32KHz sampling rate:** ready for customized digital filters with less distortion
- **30 bits effective signal:** maximize signal resolution
- **3 Tera Flops of signal processing power:** enable advanced algorithms

ComboLab

Your hemodynamic and electrophysiology recording solution on one platform

Mac-Lab

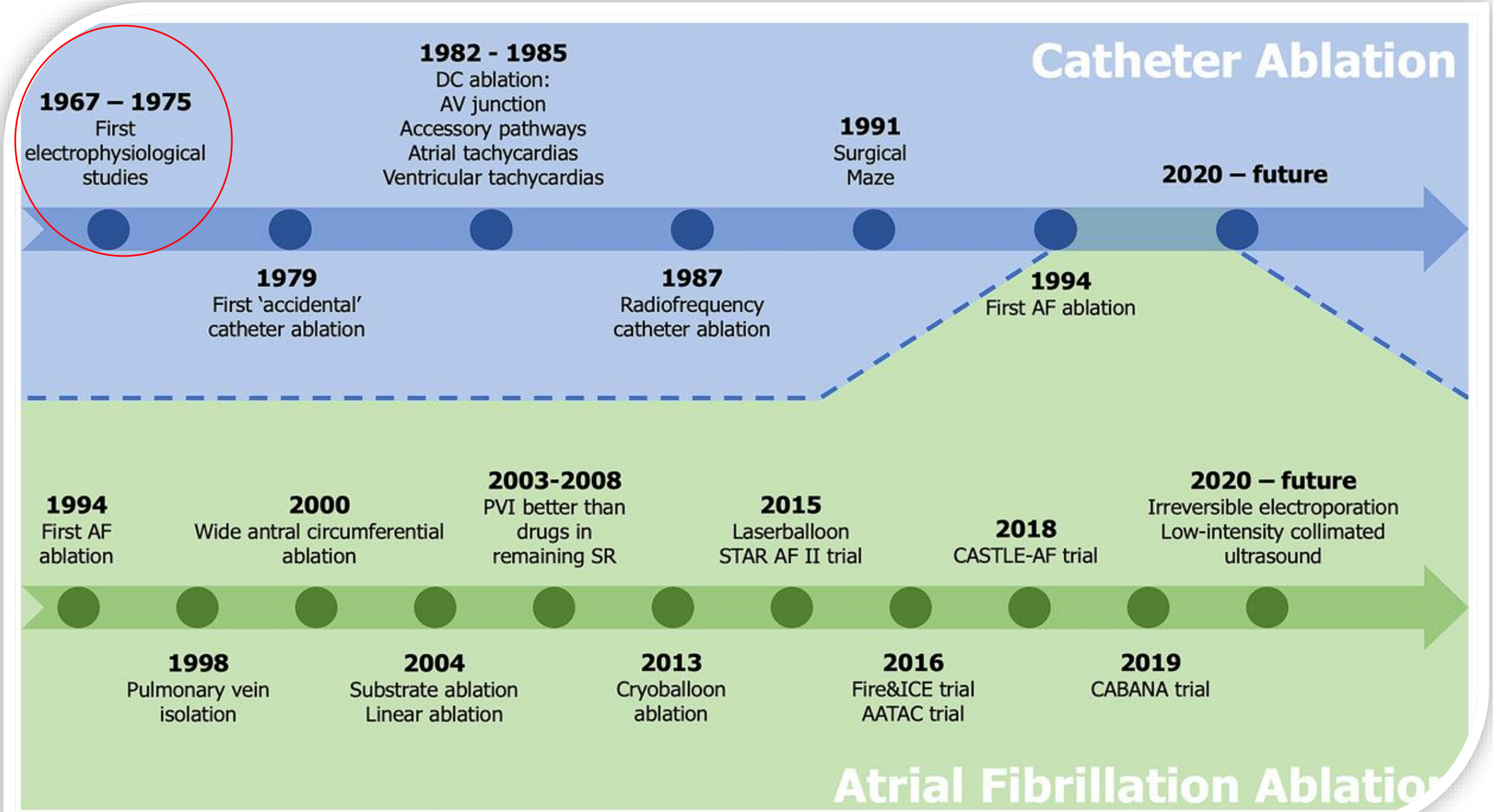
Hemodynamic recording

ComboLab

Hemodynamics and electrophysiology on a single platform

CardioLab

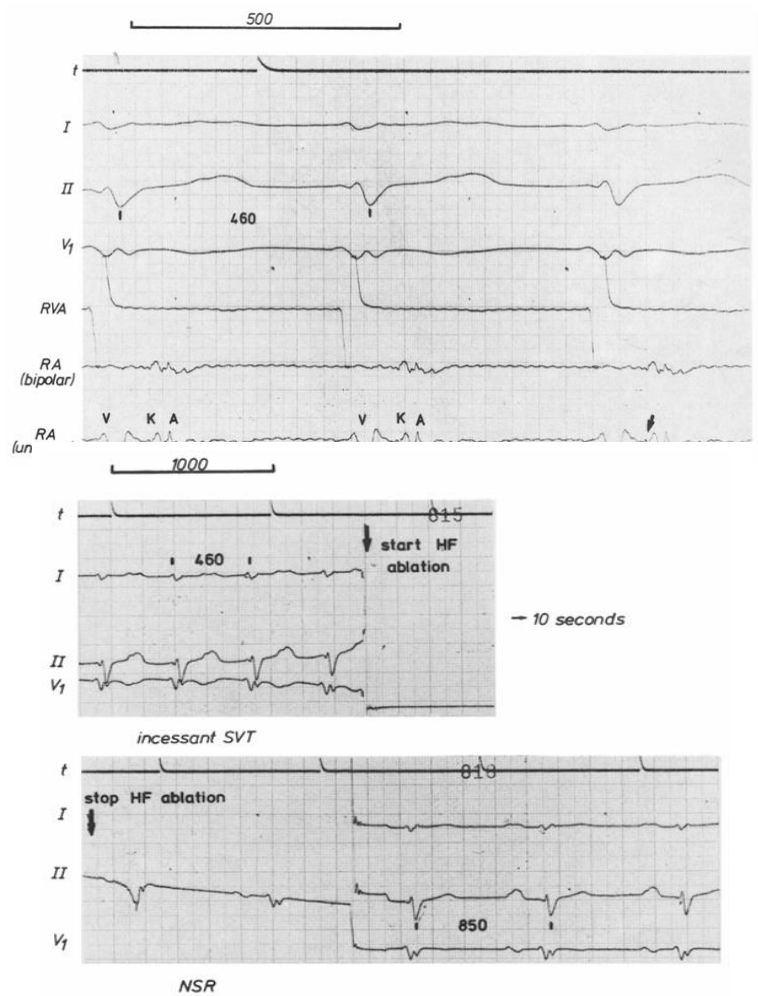
Electrophysiology recording


Catheter Ablation
1967 – 1975
First electrophysiological studies
1979
First 'accidental' catheter ablation
1982 - 1985
DC ablation:
AV junction
Accessory pathways
Atrial tachycardias
Ventricular tachycardias
1987
Radiofrequency catheter ablation
1991
Surgical Maze
1994
First AF ablation
2020 – future
1994
First AF ablation
1998
Pulmonary vein isolation
2000
Wide antral circumferential ablation
2003-2008
PVI better than drugs in remaining SR
2004
Substrate ablation
Linear ablation
2013
Cryoballoon ablation
2015
Laserballoon
STAR AF II trial
2016
Fire&ICE trial
AATAC trial
2018
CASTLE-AF trial
2019
CABANA trial
2020 – future
Irreversible electroporation
Low-intensity collimated ultrasound
Atrial Fibrillation Ablation

High Frequency Alternating Current Ablation of an Accessory Pathway in Humans

MARTIN BORGGREFE, MD, THOMAS BUDDE, MD, ANDREA PODCZECK, MD, GÜNTER BREITHARDT, MD

Düsseldorf, West Germany



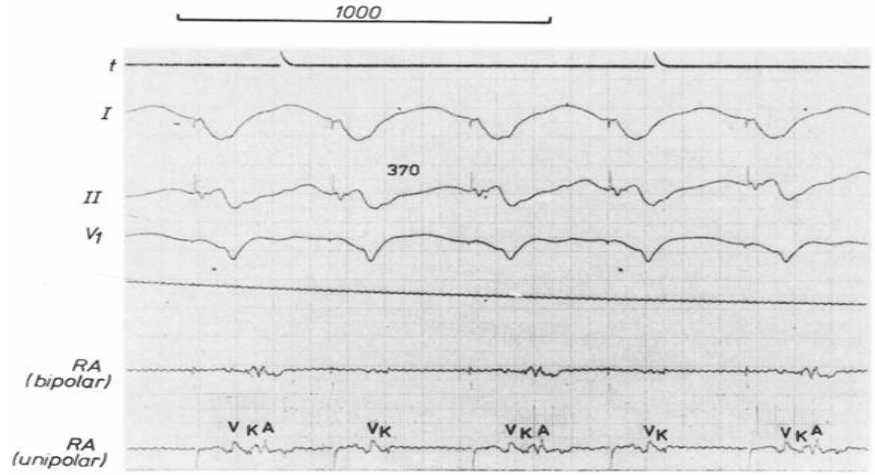


Figure 5. Recordings of leads I, II and V_1 during the high frequency ablation procedure. During incessant supraventricular reentrant tachycardia (SVT) with a cycle length of 460 ms high frequency (HF) alternating current ablation was started **(arrow).** After 10 seconds, the device automatically switched off and normal sinus rhythm (NSR) with a cycle length of 850 ms resumed. See text for further explanations.

(J Am Coll Cardiol 1987;10:576–82)

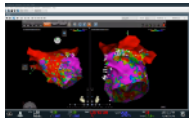
A major player in the hemodynamic and electrophysiology recording space for ~30 years

1989: Mac-Lab v1.0 and Prucka EP system

Pre-2000

Version 5.x DOS

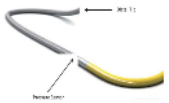
Acquisition of Marquette Electronics and Prucka™ Engineering



1st to introduce Carto interface

2003

Version 6.0



1st system to have integrated FFR

2009

Version 6.8

1st to integrate with ultrasound

2011

Version 6.9

1st to offer networked, MultiPath workflow

2013

Version 6.9.5

1st to have a flexible antivirus solution

2015

Version 6.9.6

1st HD quality video distributed up to 9 displays

2019

AltiX Edition

1st to offer in-motion and rest data encryption

2020

AltiX BT21

1st to launch in-room apps for drive workflow

1st system to have integrated DFR™

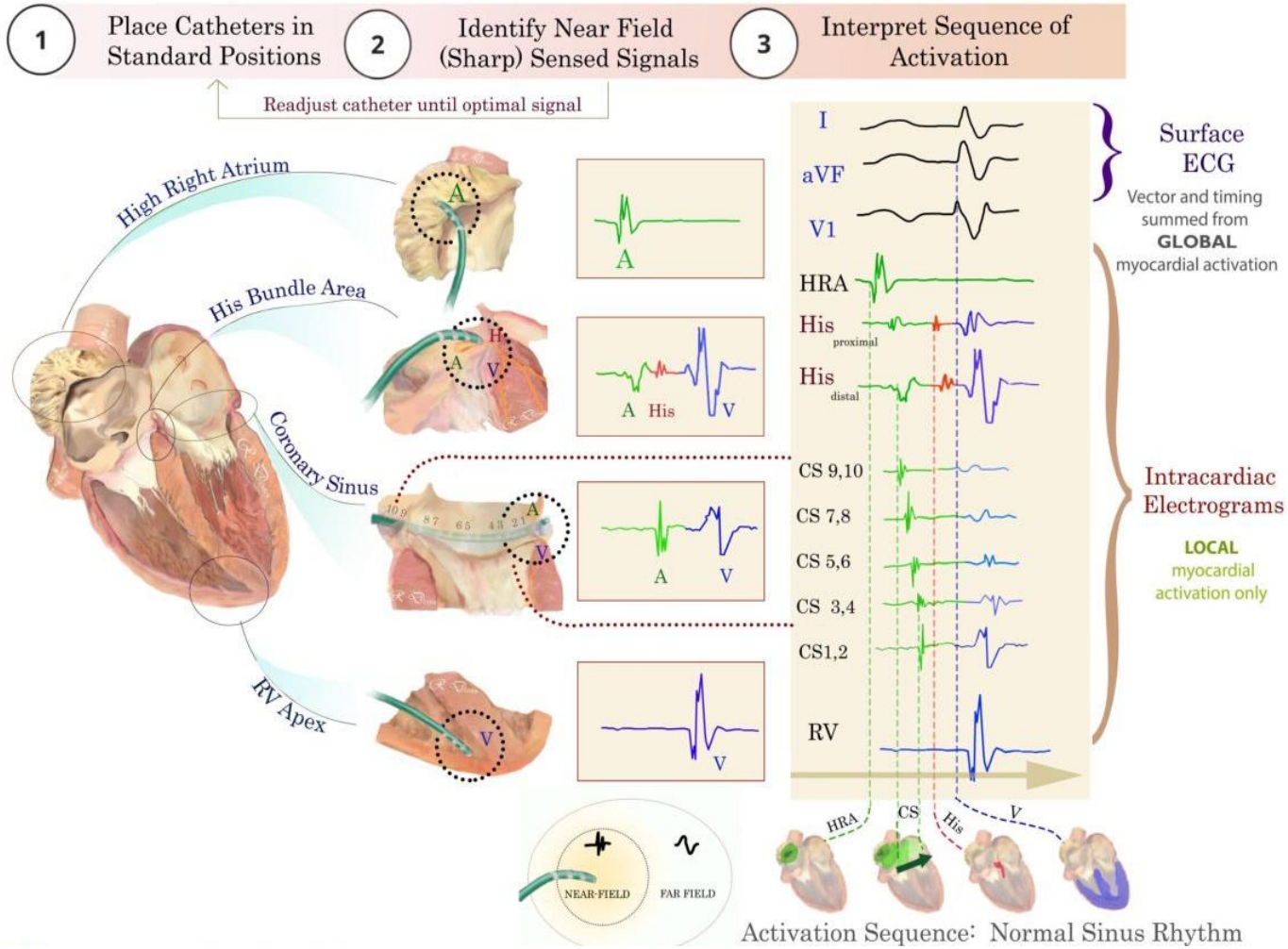
Today

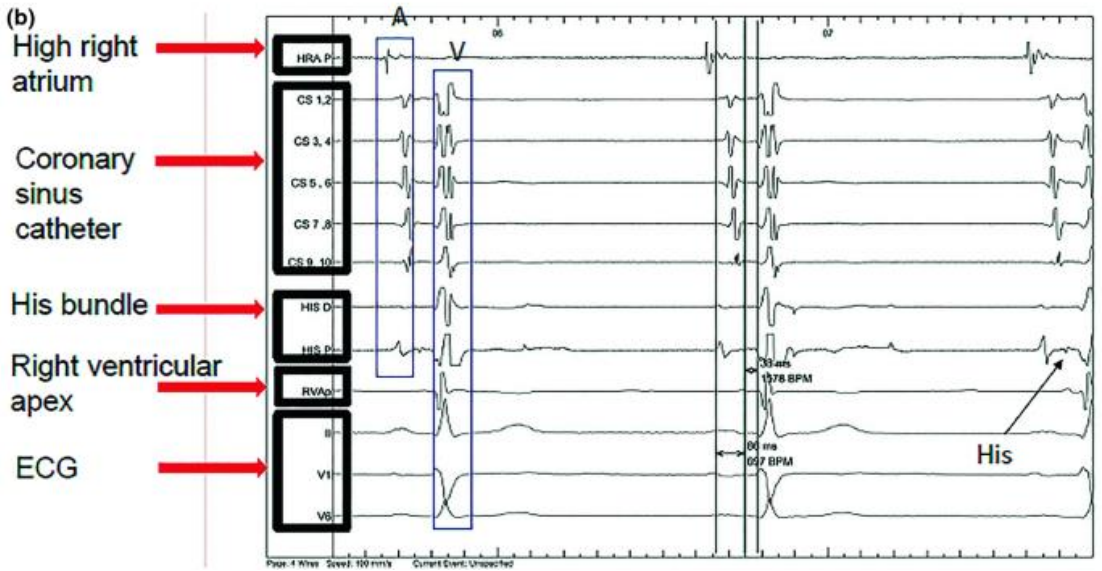
AltiX BT22

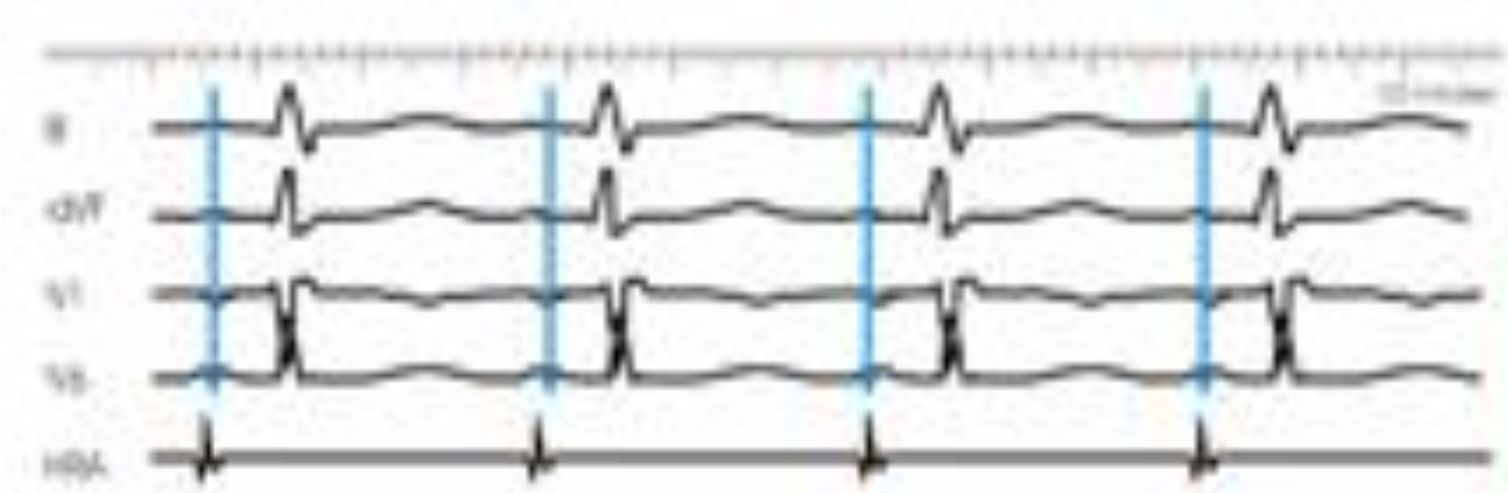
Accelerated innovation cycles

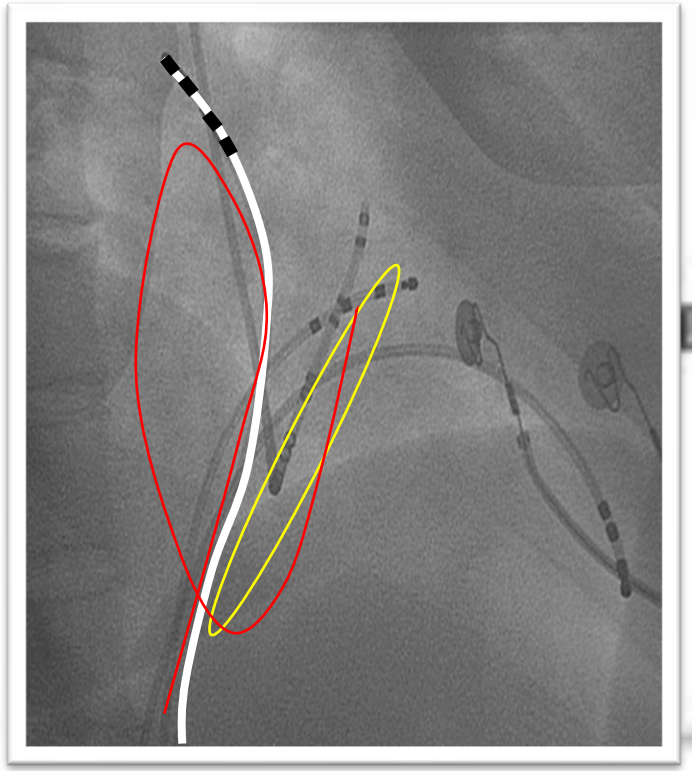
1st digital amplifier to provide 10x noise reduction

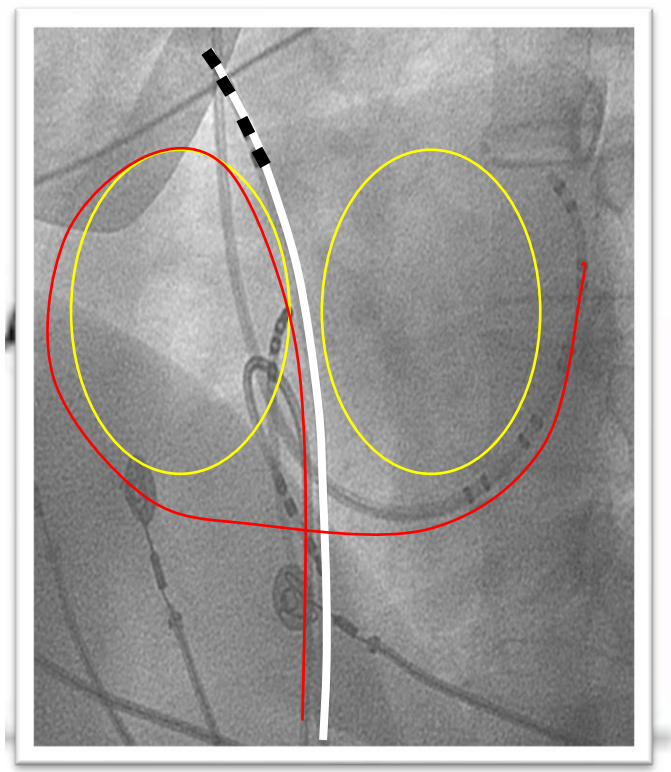
What is important to get an ideal EGM?

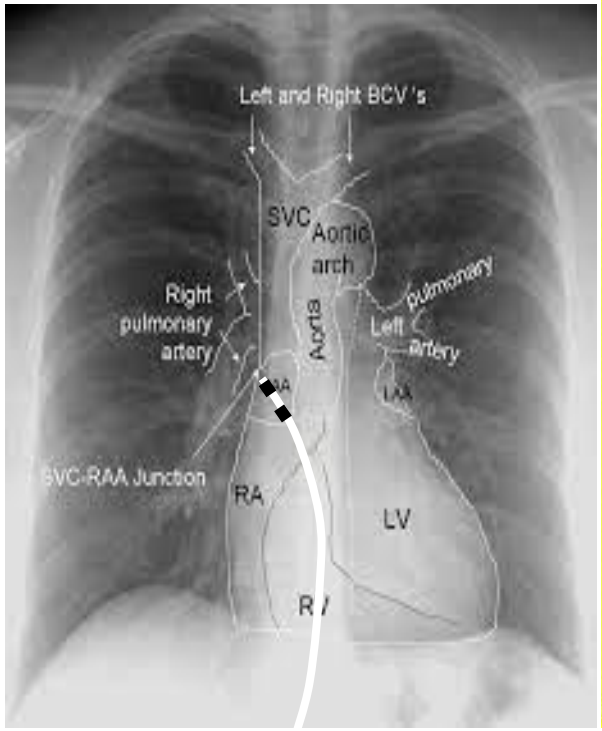




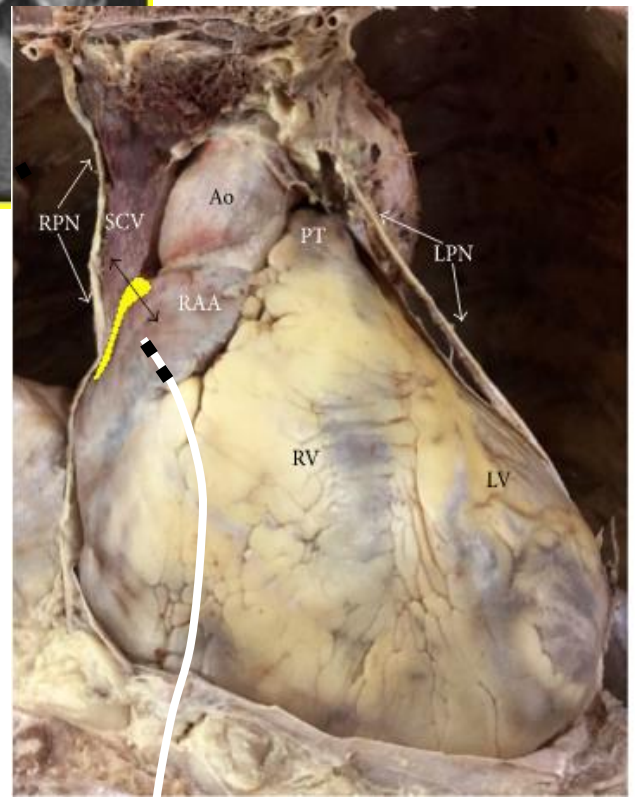

II
aVF
V1
V5
HRA

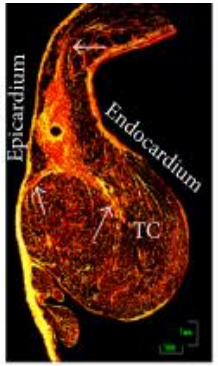




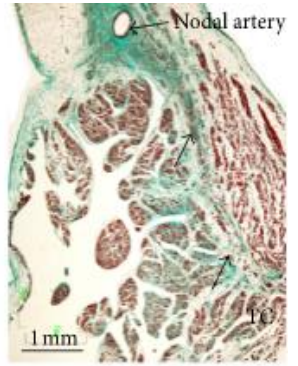

Left and Right BCV's
SVC
Aortic arch
Right pulmonary artery
Aorta
pulmonary
Left
artery
SVC-RAA Junction
RA
LV
RV


Anonymous A
trachea
SVC
PA
ada
Sino-tubular junction
Ao
AV
LV
alpm
Suprahepatic vv
pmpm
B

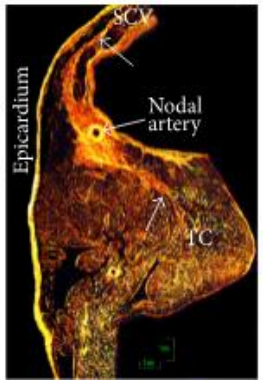

RPN
SCV
Ao
PT
LPN
RAA
RV
LV

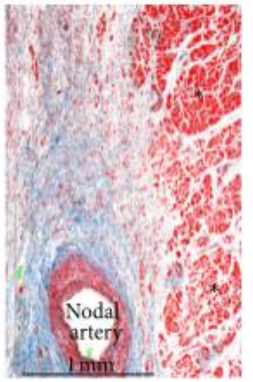

Epicardium
Endocardium
TC

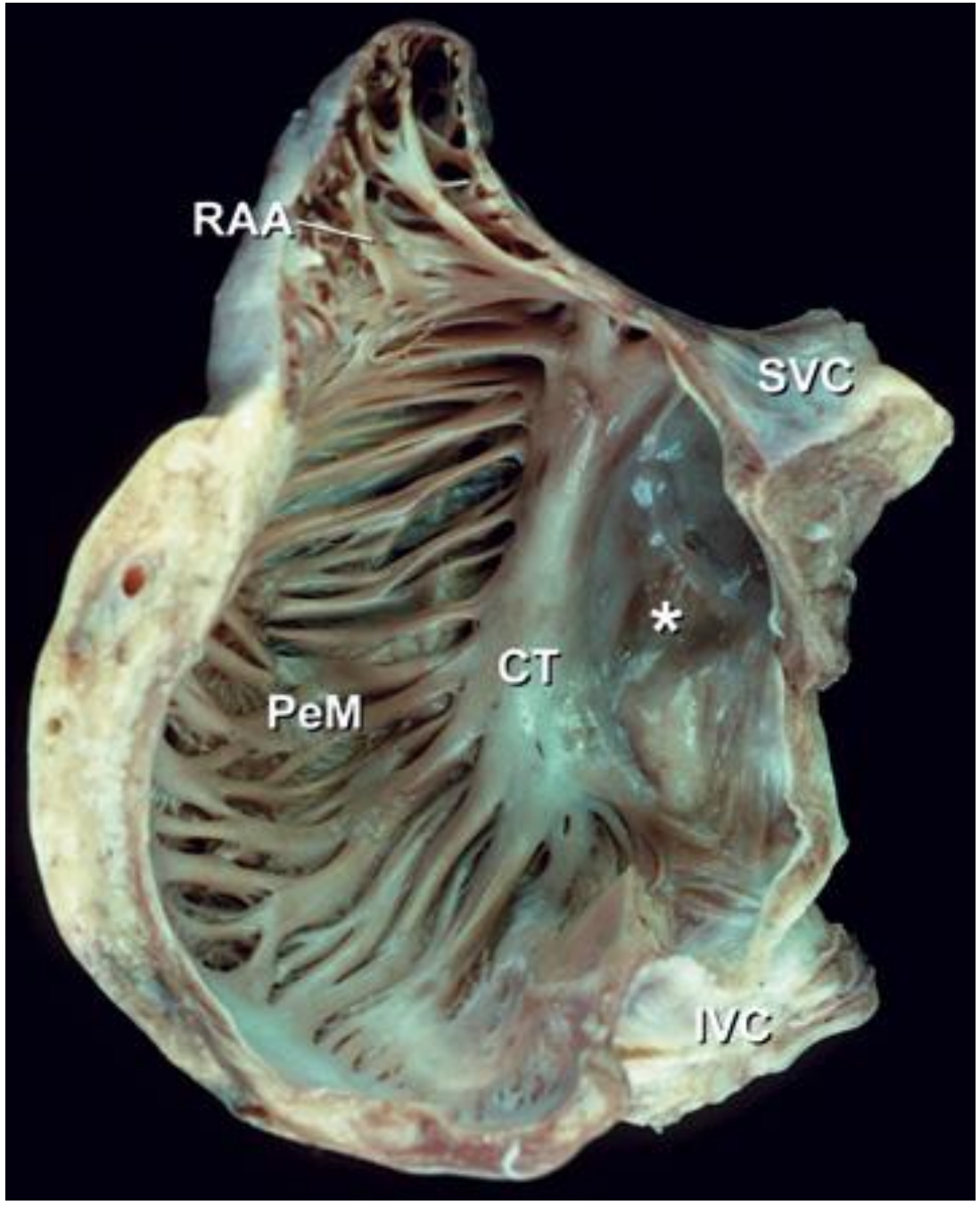
(b)

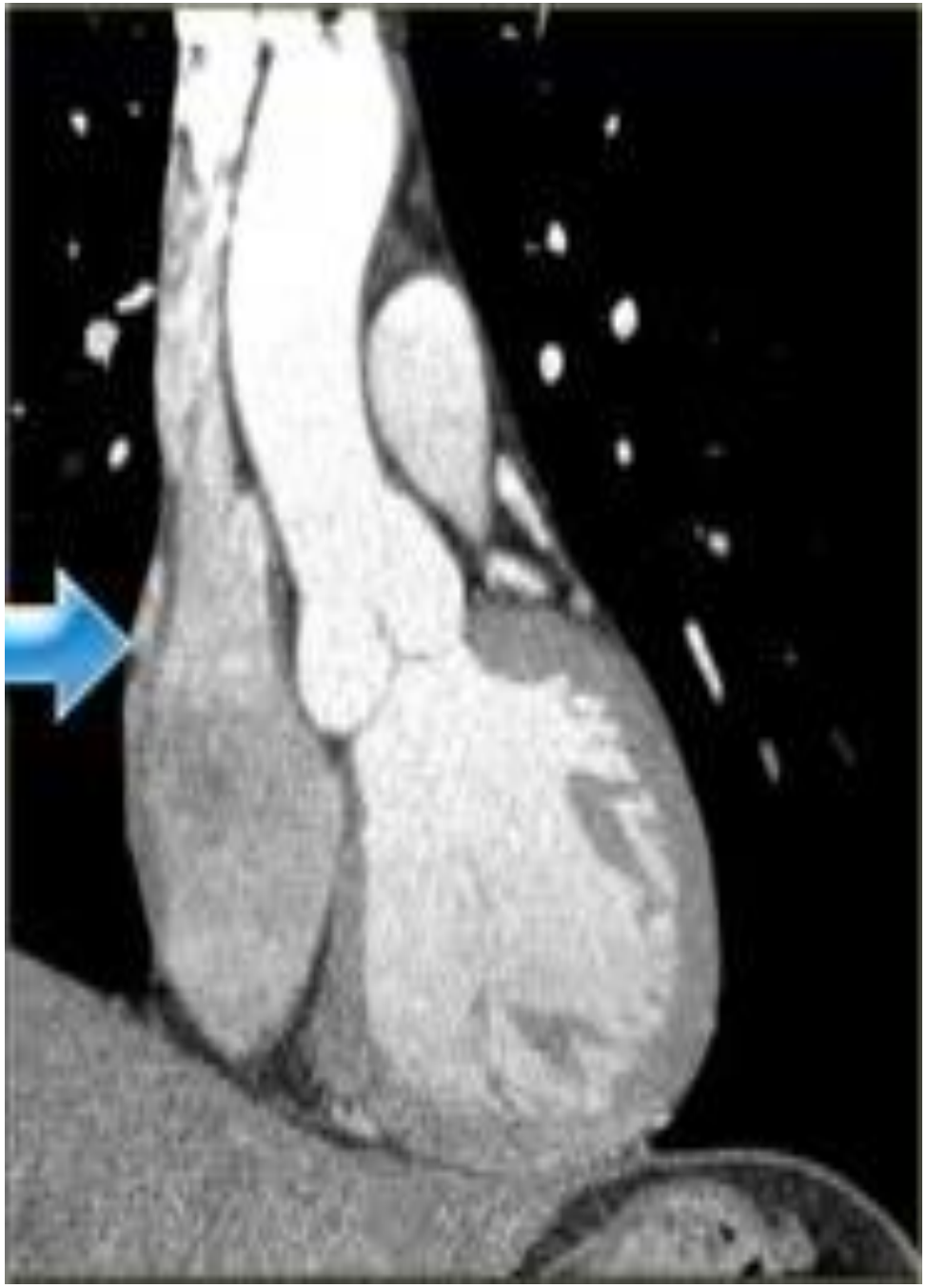

Nodal artery
1 mm
TC

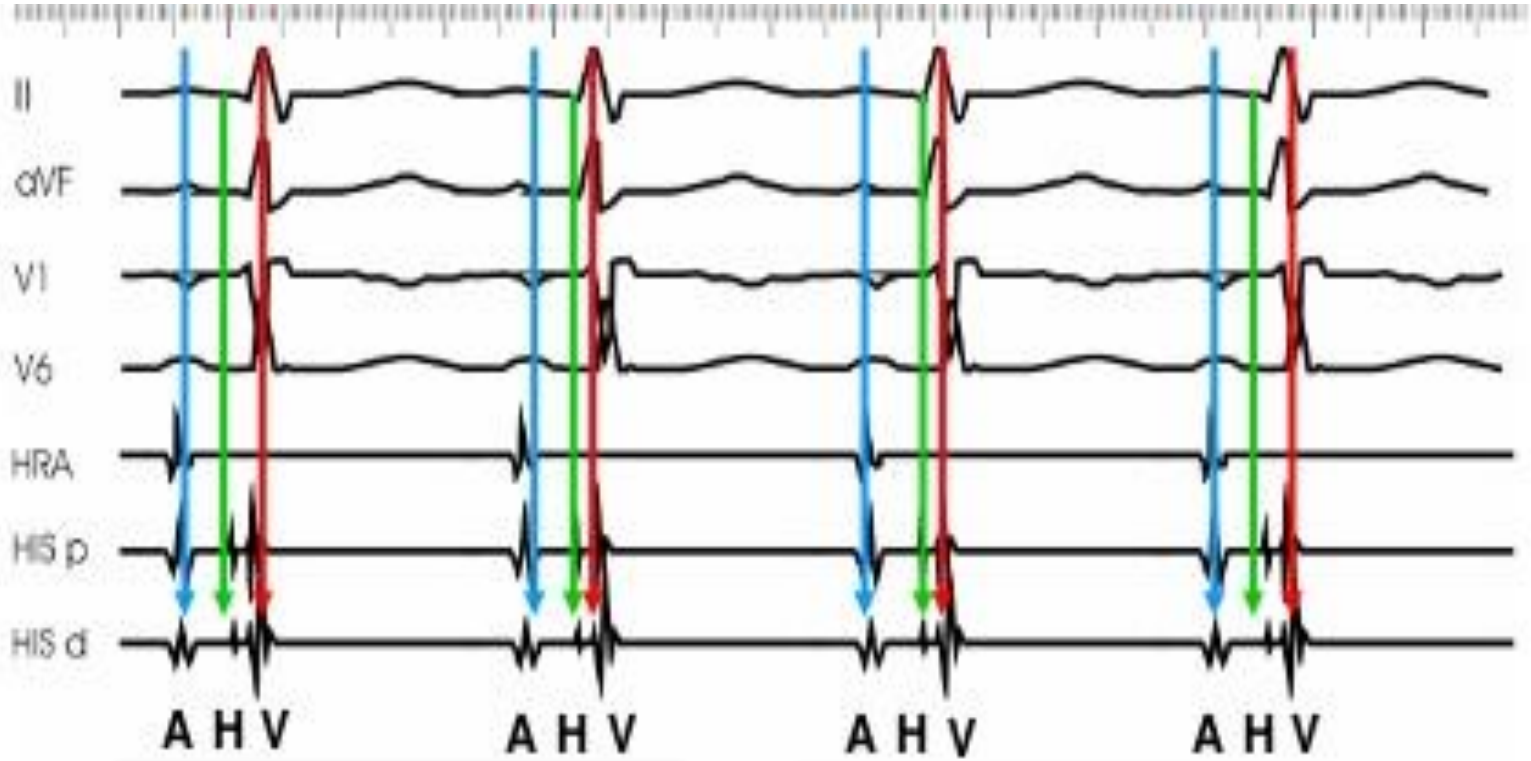
(d)

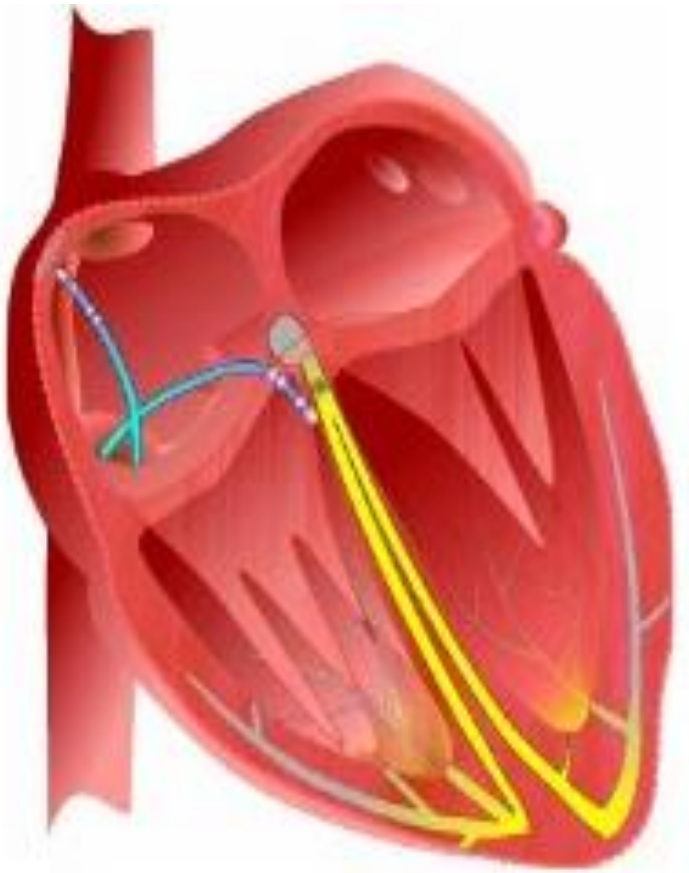

SCV
Epicardium
Nodal artery
TC

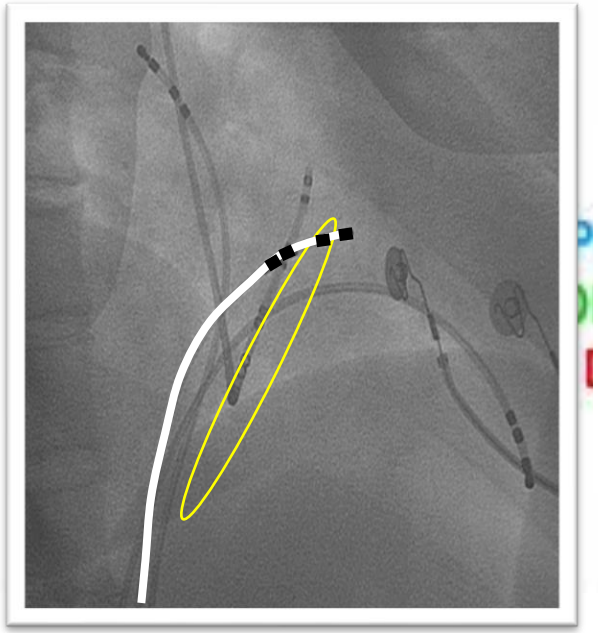

Nodal artery
1 mm

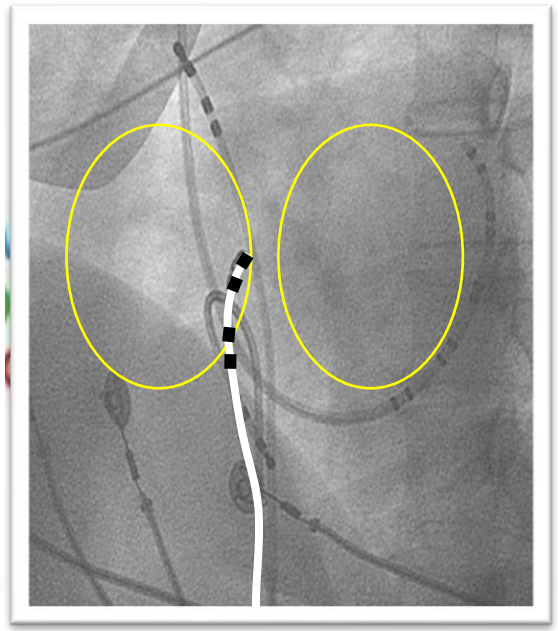

RAA
SVC
*
CT
PeM
IVC

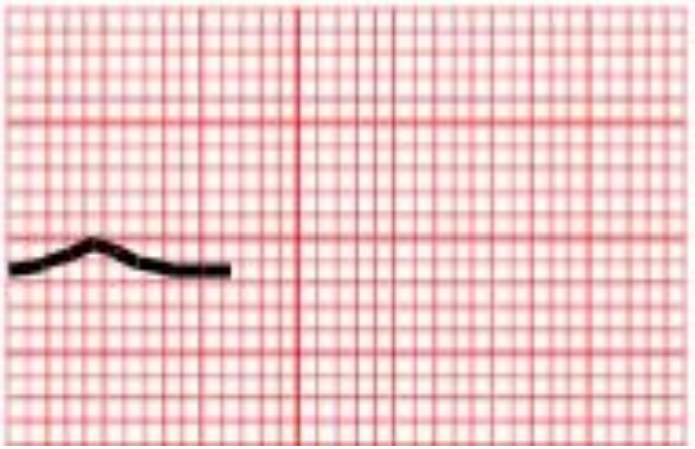


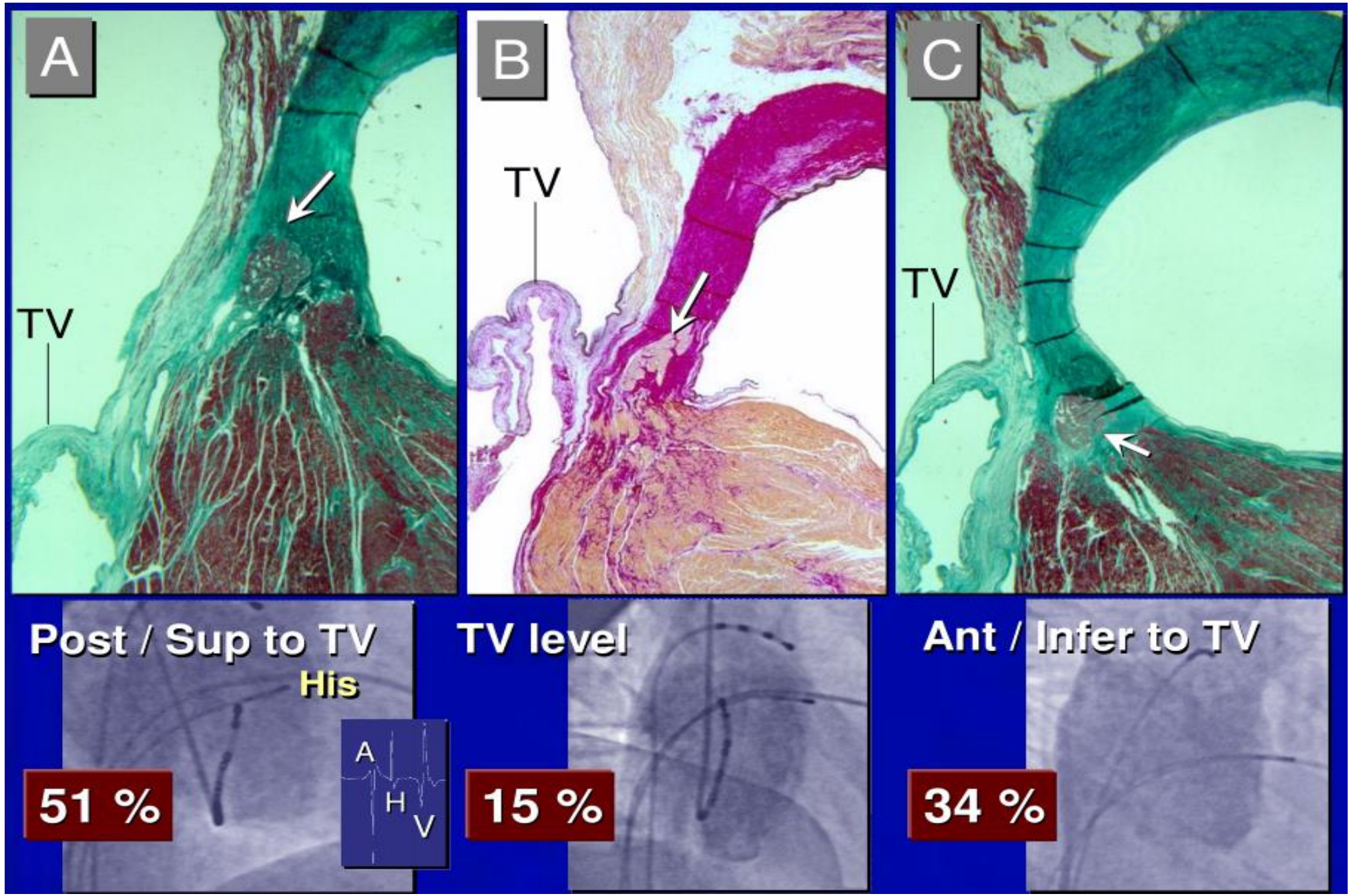

II
aVF
V1
V6
HRA
HIS p
HIS d
A H V
A H V
A H V
A H V

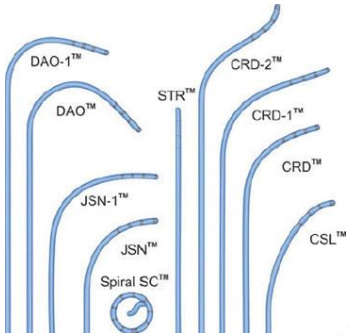


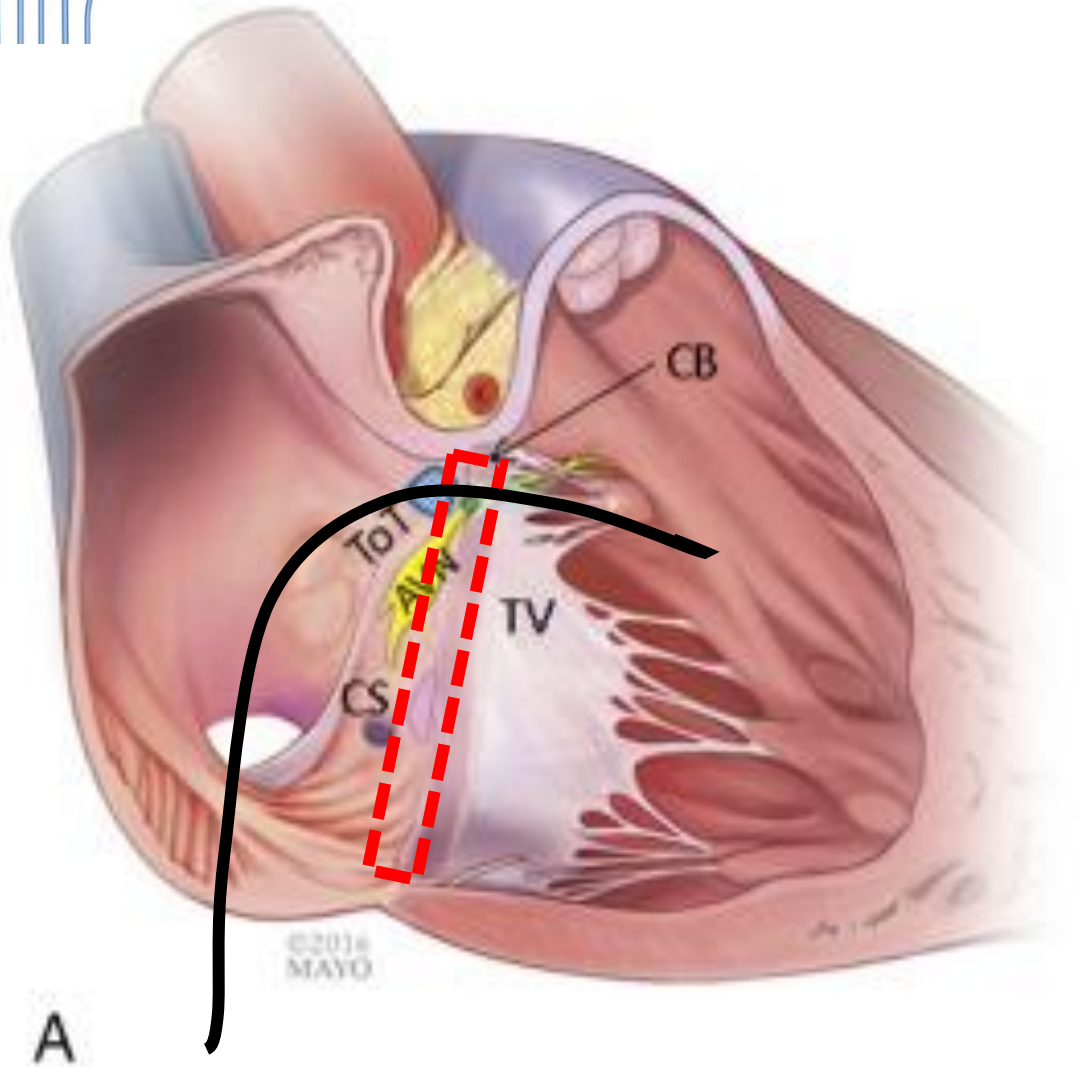


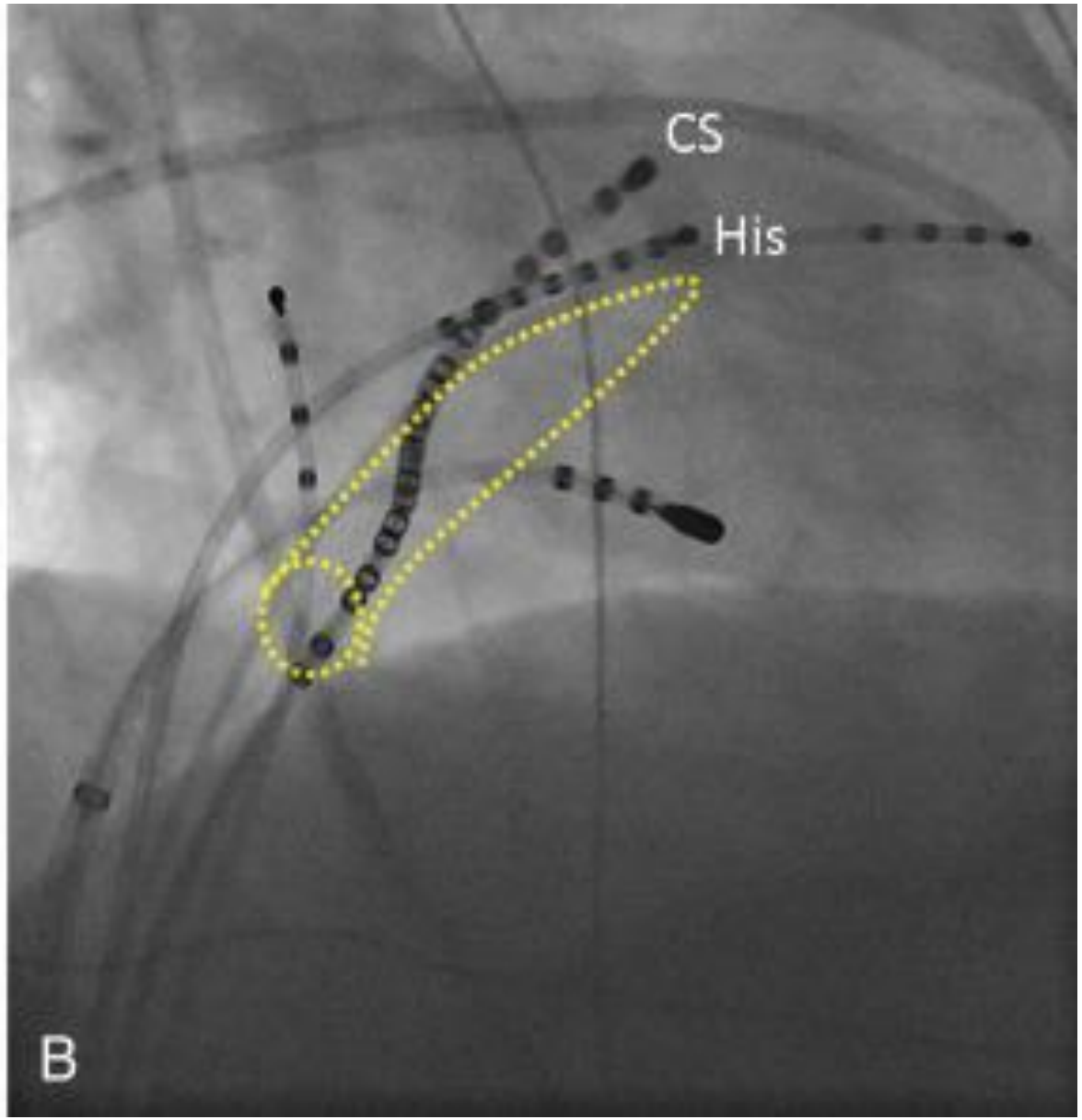


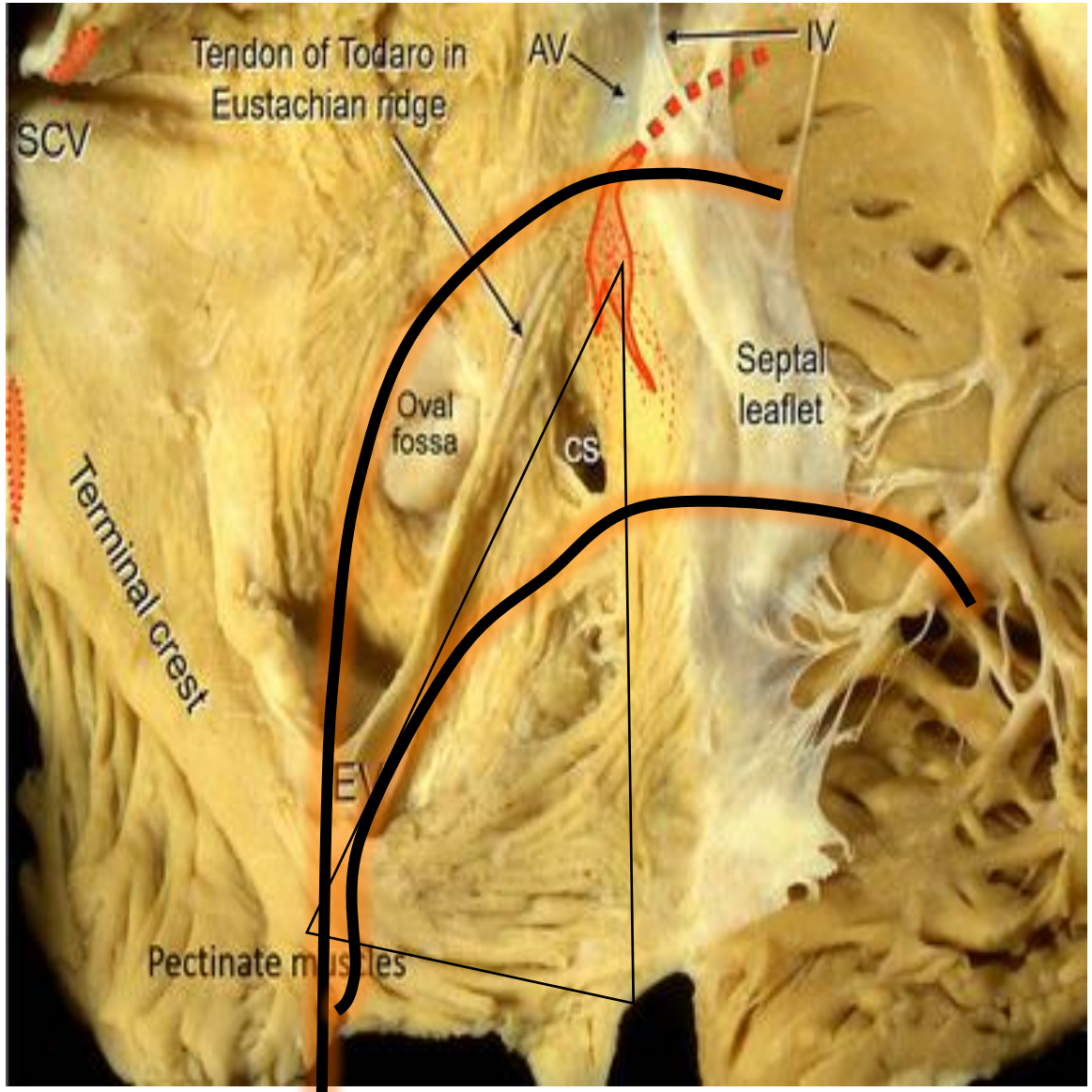


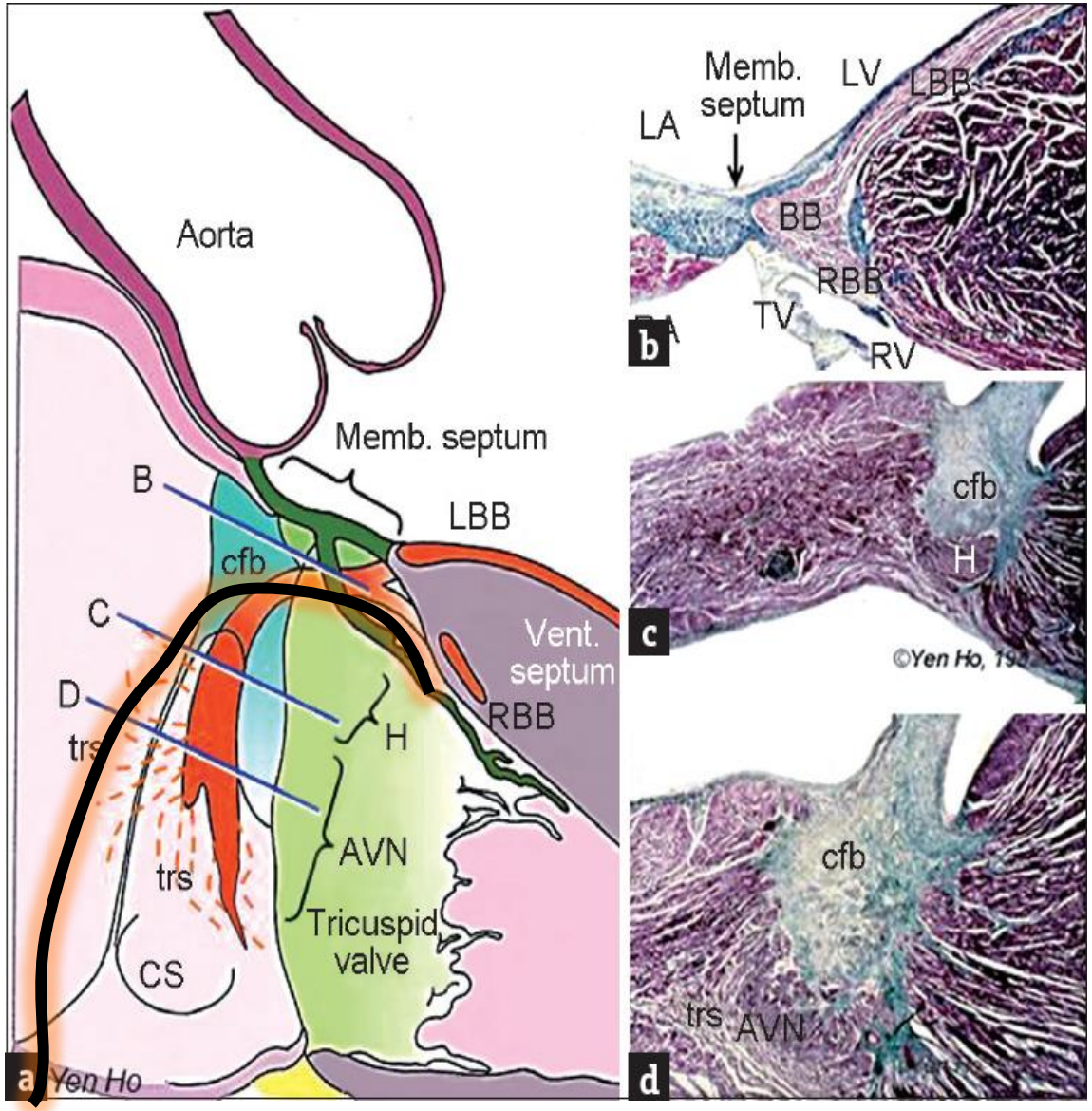

A
TV
B
TV
C
TV
Post / Sup to TV
His
A
H
V
51 %
TV level
15 %
Ant / Infer to TV
34 %

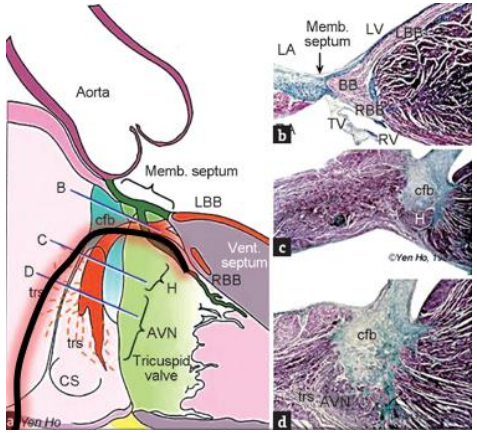

DAO-1™
DAO™
STR™
CRD-2™
CRD-1™
CRD™
JSN-1™
JSN™
Spiral SC™
CSL™

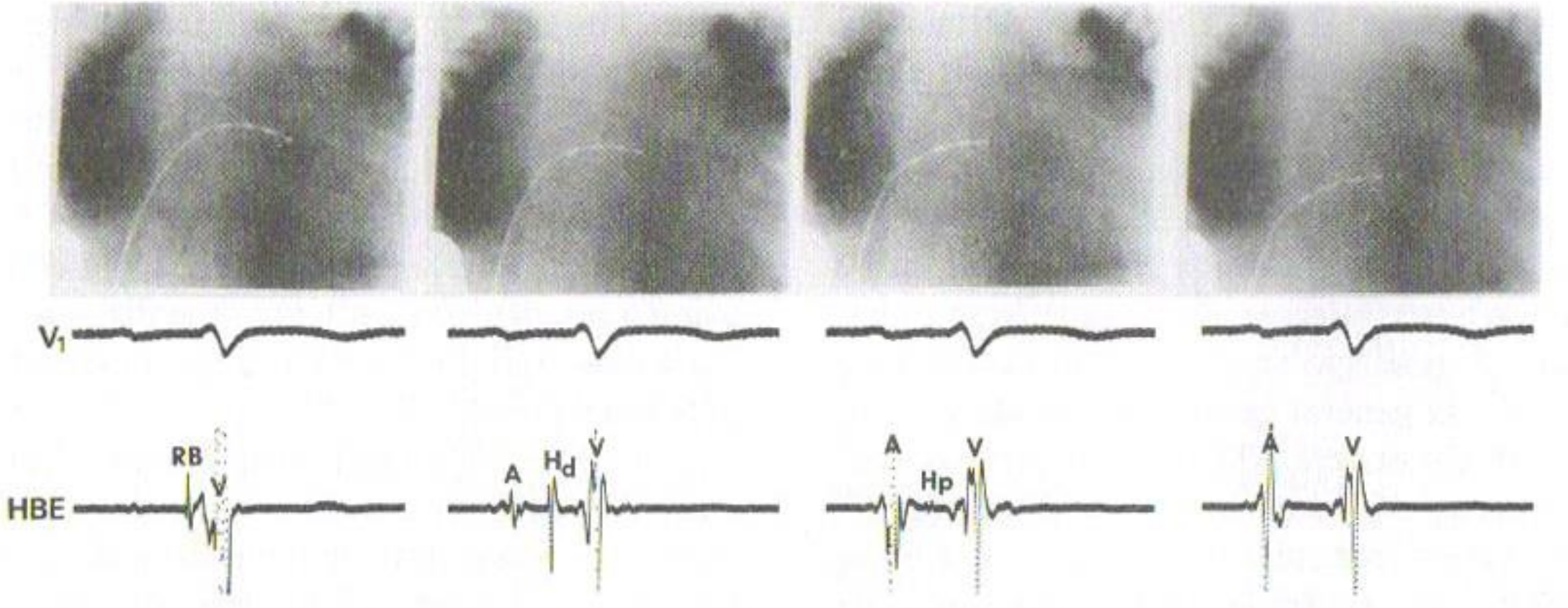

CB
ToT
AVN
TV
CS
©2018
MAYO
A


CS
His
B

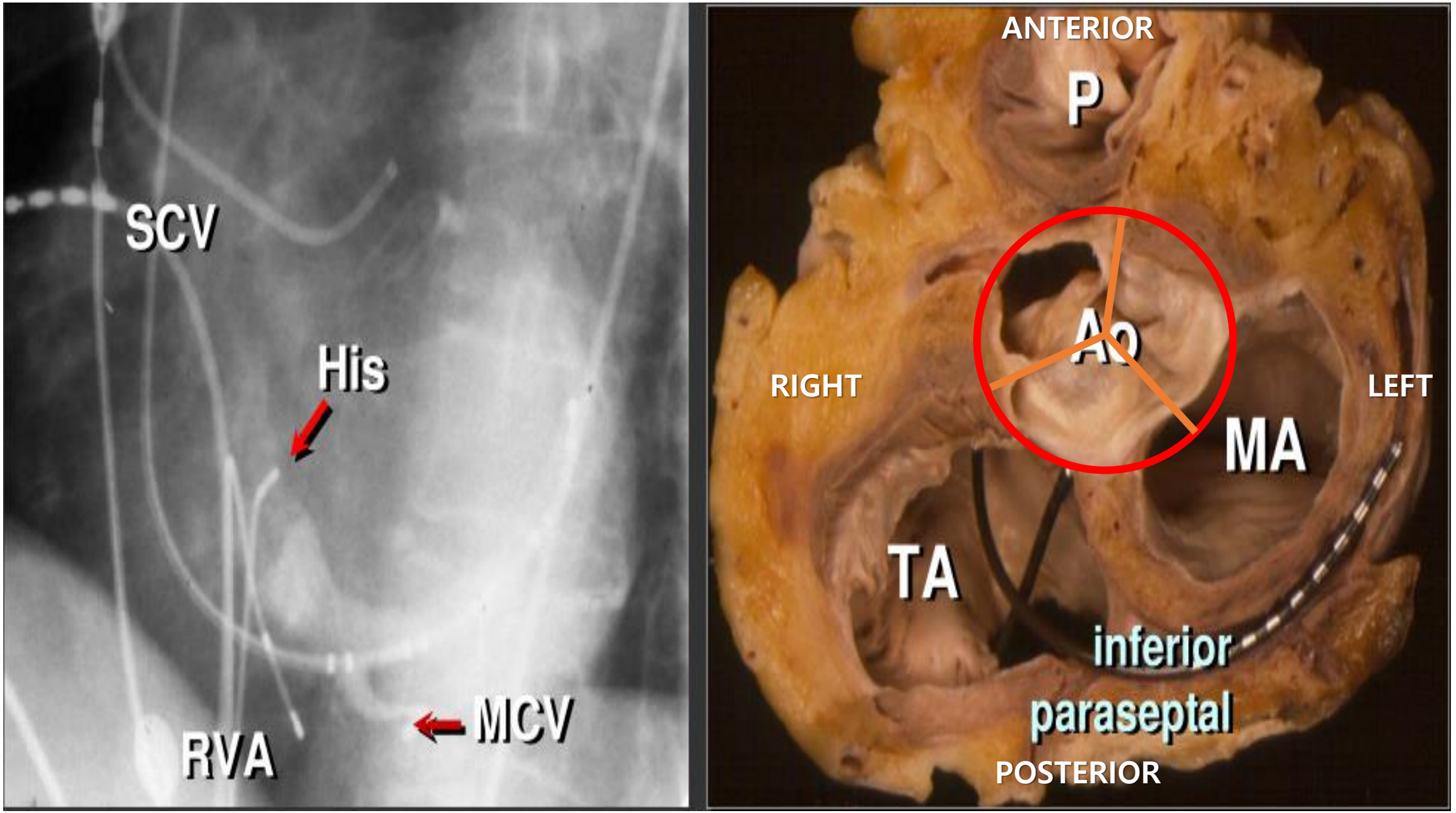

Tendon of Todaro in
Eustachian ridge
AV
IV
SCV
Septal
leaflet
Oval
fossa
CS
Terminal crest
Pectinate muscles

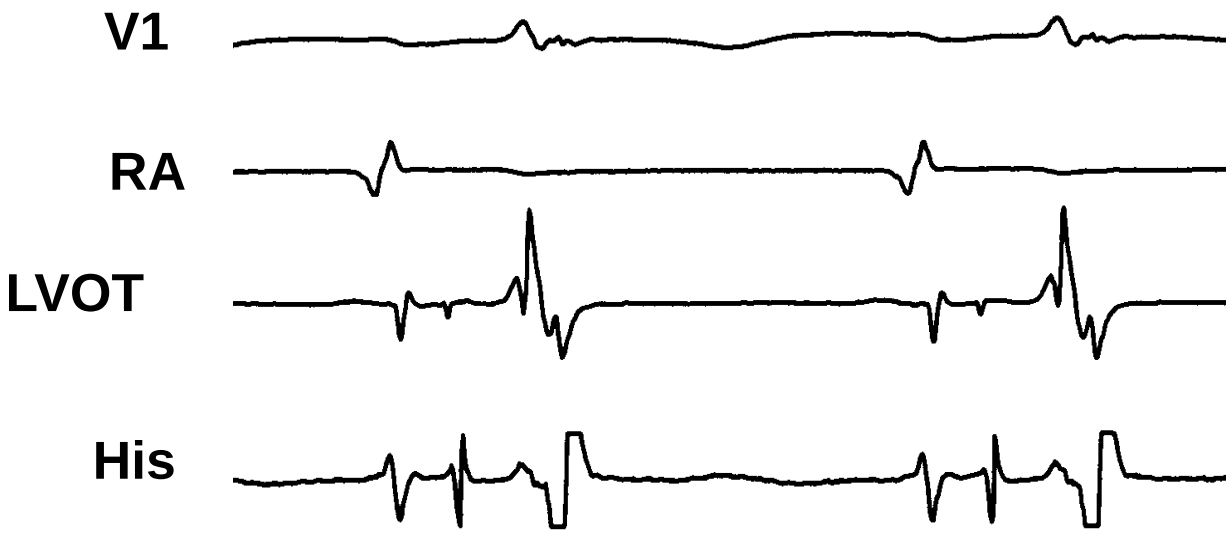

Aorta
Memb. septum
B
LBB
cfb
C
Vent.
septum
D
RBB
H
trs
AVN
trs
Tricuspid
valve
CS
a Yen Ho
Memb.
septum
LV
LBB
LA
BB
RBB
TV
RV
b
cfb
H
c
©Yen Ho, 19
cfb
trs
AVN
d

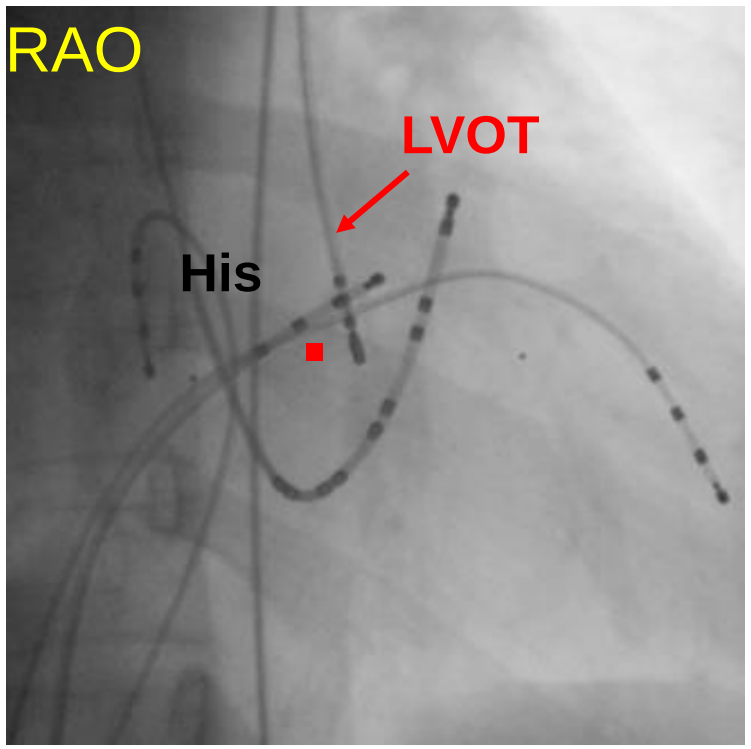


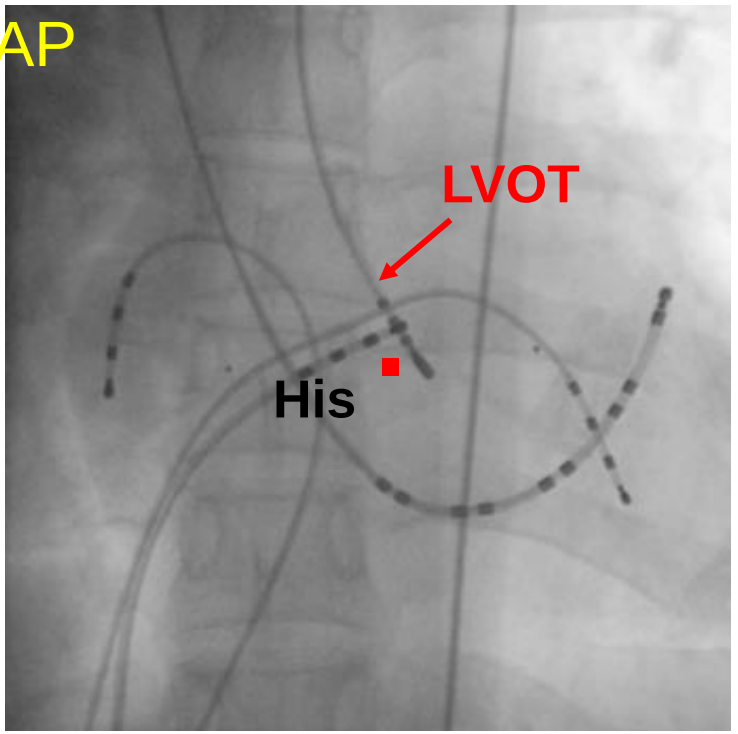


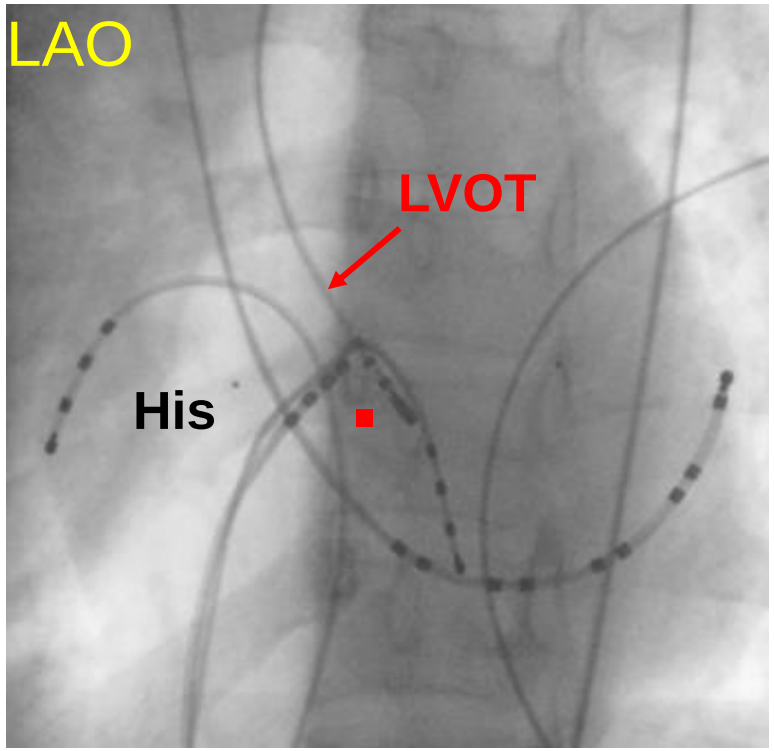
Recording the His bundle electrogram during catheter withdrawing

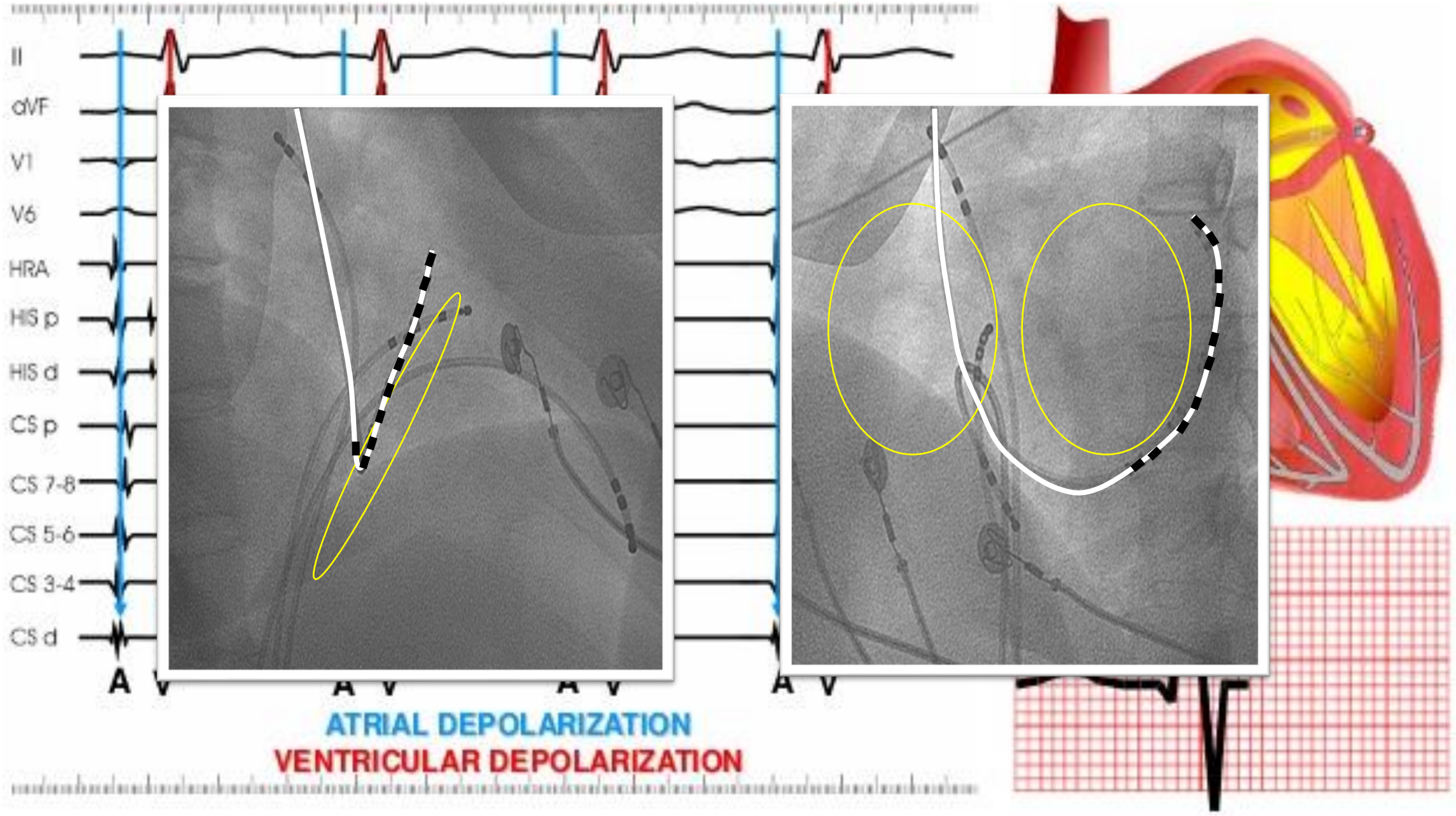

SCV
His
MCV
RVA
ANTERIOR
P
Ao
RIGHT
LEFT
MA
TA
inferior
paraseptal
POSTERIOR

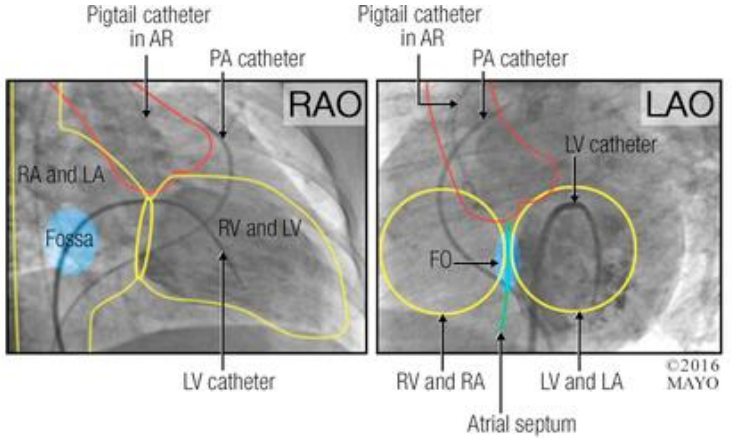

V1
RA
LVOT
His

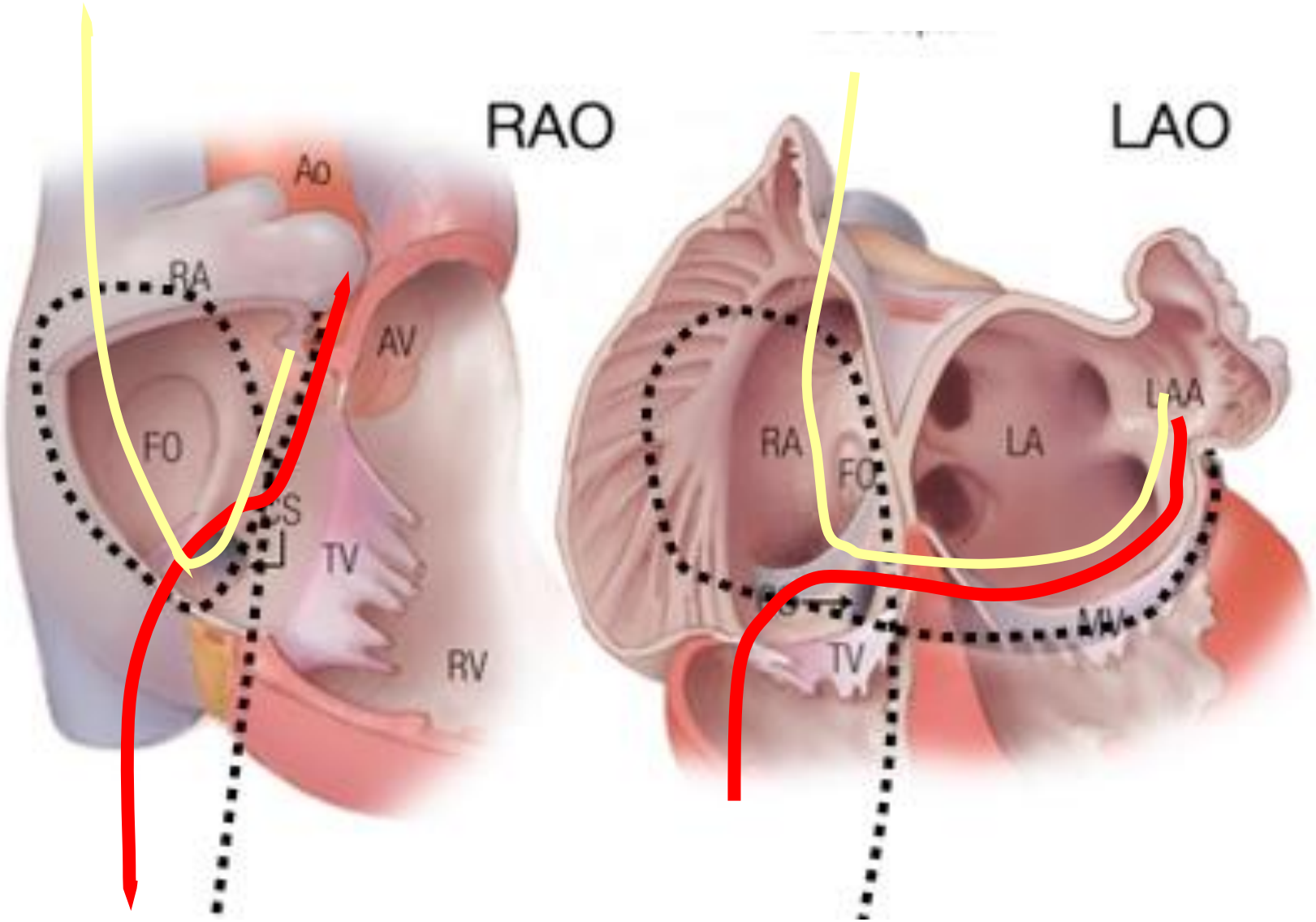

RAO
LVOT
His

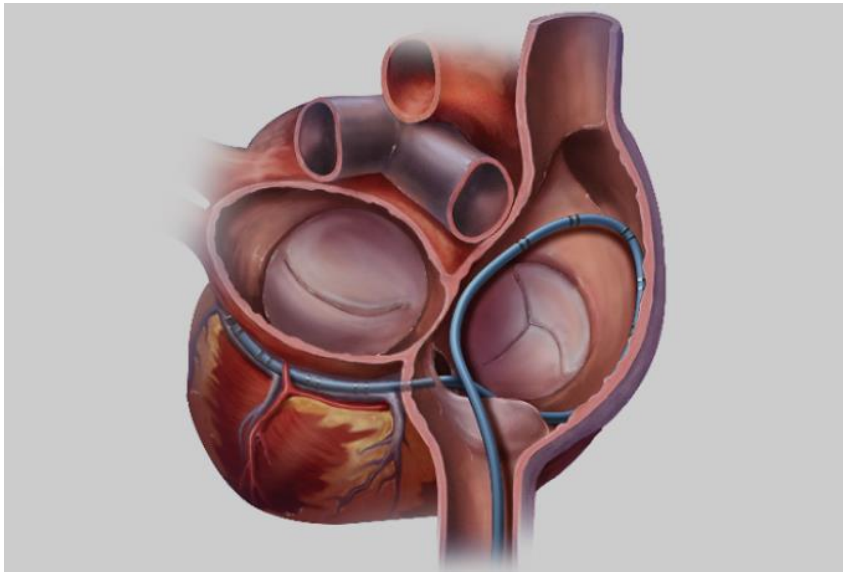

AP
LVOT
His

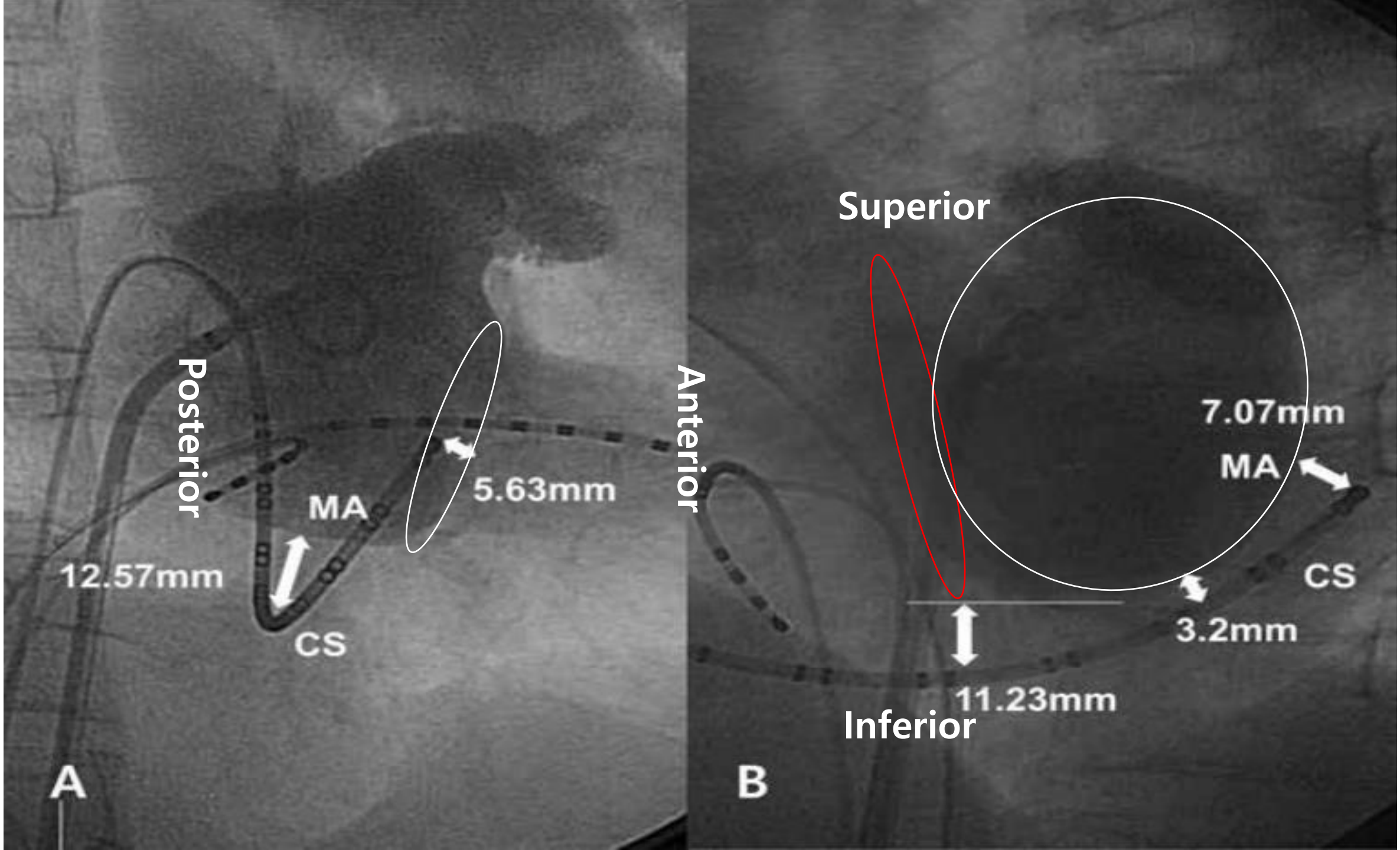

LAO
LVOT
His

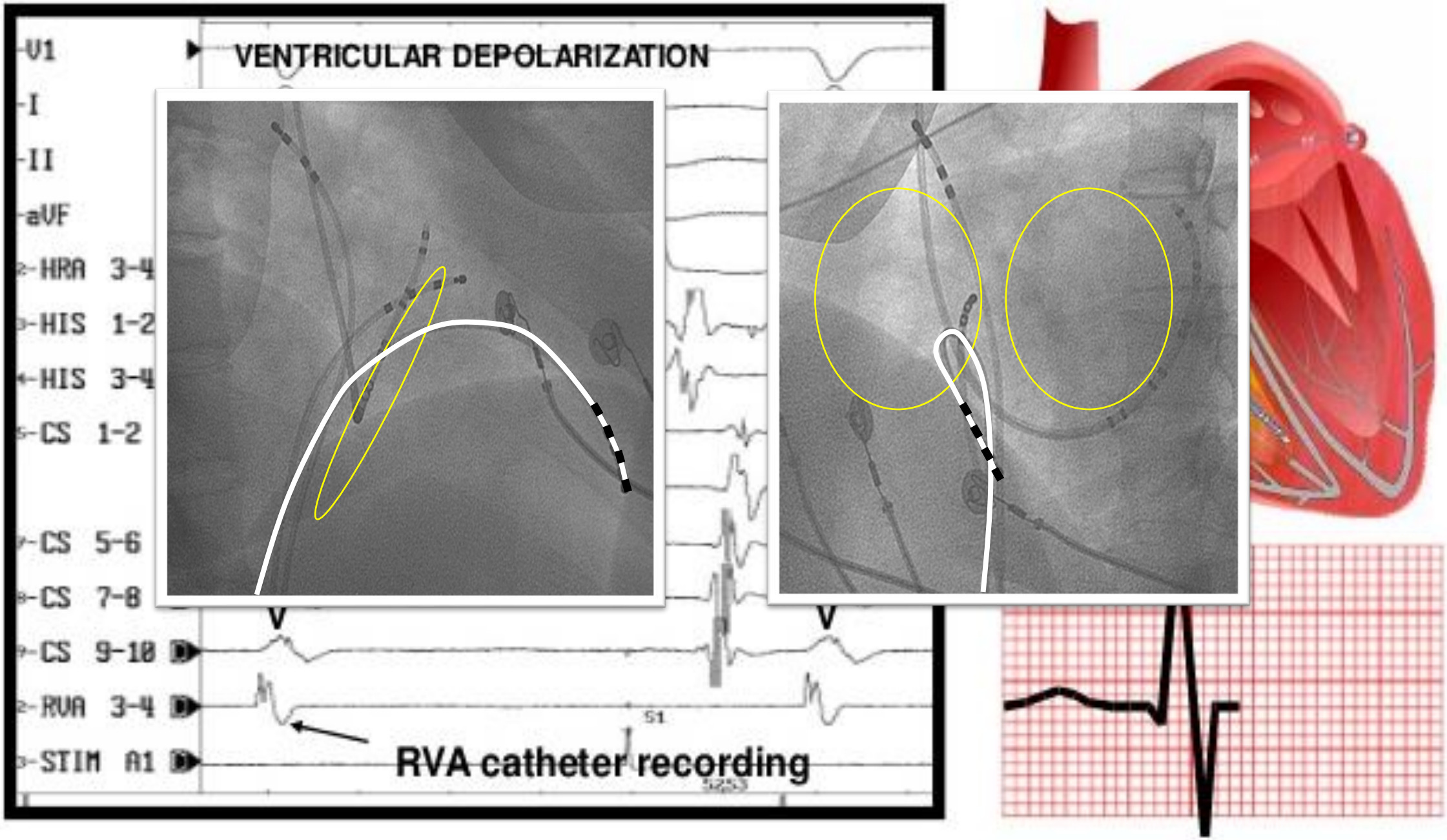

II
aVF
V1
V6
HRA
HIS p
HIS d
CS p
CS 7-8
CS 5-6
CS 3-4
CS d
A V
A V
A V
A V
ATRIAL DEPOLARIZATION
VENTRICULAR DEPOLARIZATION

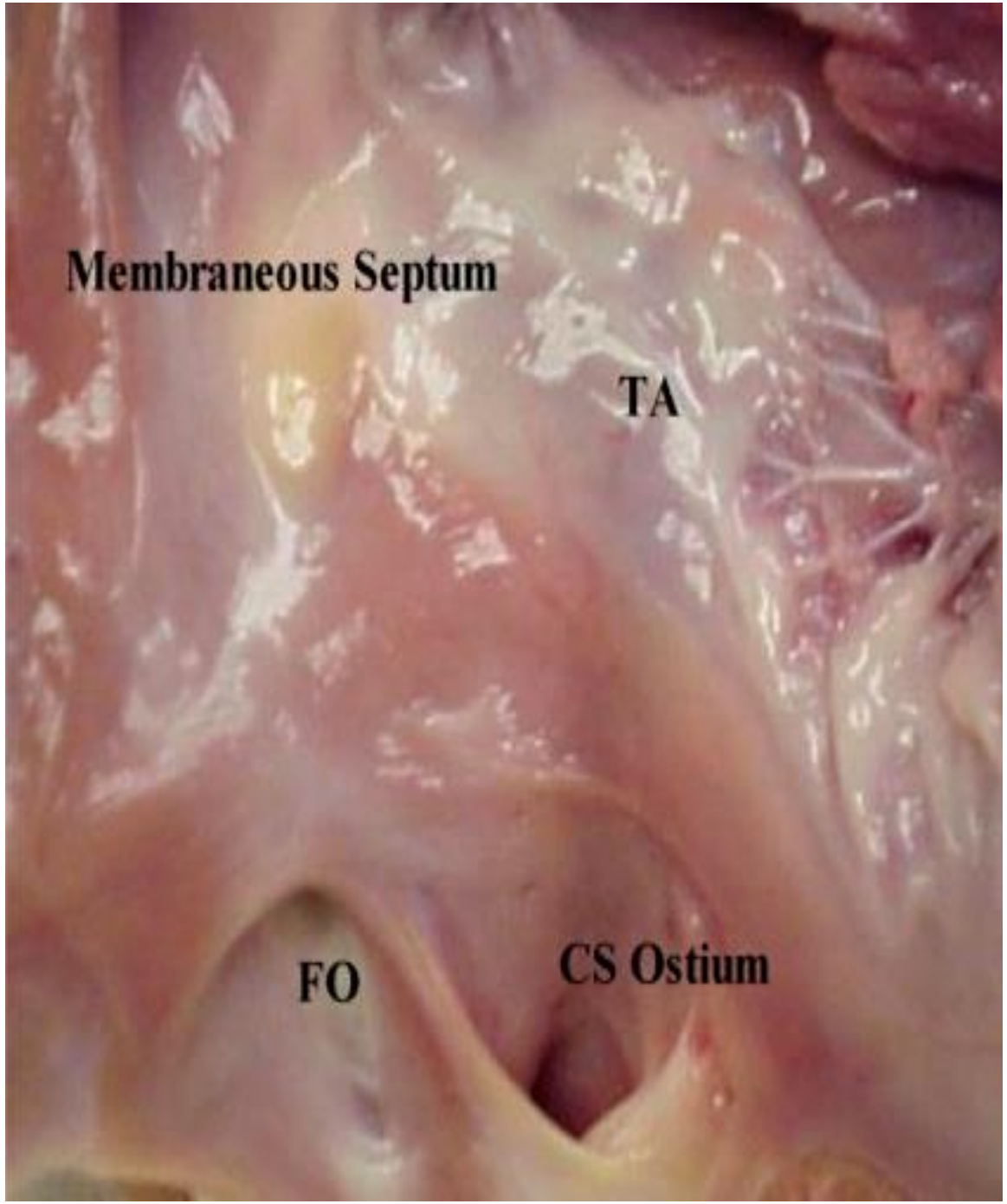

Pigtail catheter in AR
PA catheter
RAO
RA and LA
Fossa
RV and LV
LV catheter
Pigtail catheter in AR
PA catheter
LAO
LV catheter
FO
RV and RA
LV and LA
Atrial septum
©2016 MAYO

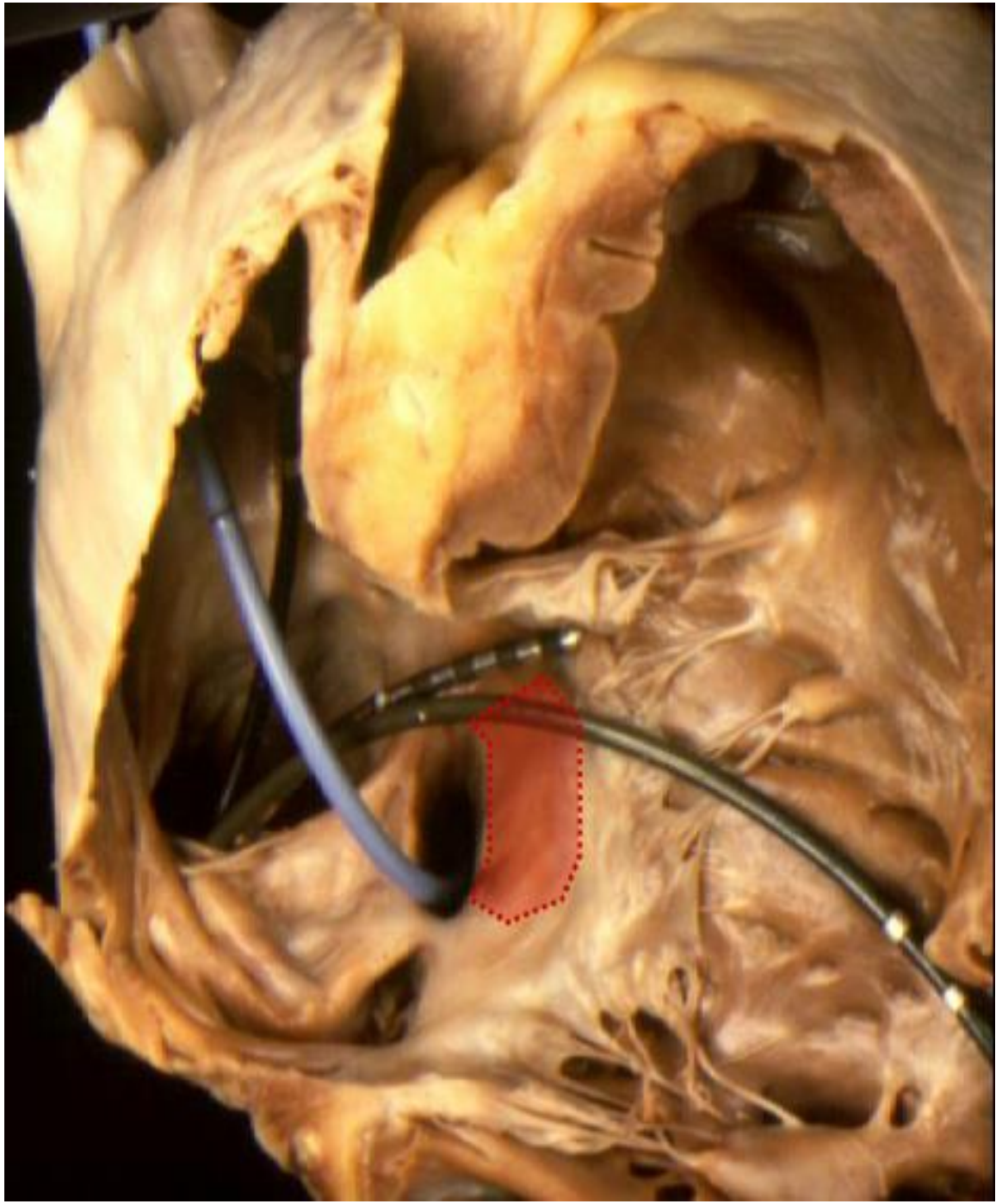

RAO
LAO
Ao
RA
AV
FO
S
TV
RV
RA
FO
LA
LAA
TV




Posterior
Anterior
MA
5.63mm
12.57mm
CS
A
Superior
7.07mm
MA
CS
3.2mm
11.23mm
Inferior
B


V1
I
II
aVF
HRA 3-4
HIS 1-2
HIS 3-4
CS 1-2
CS 5-6
CS 7-8
CS 9-10
RVA 3-4
STIM A1
VENTRICULAR DEPOLARIZATION
V
V
S1
RVA catheter recording


Membraneous Septum
TA
FO
CS Ostium



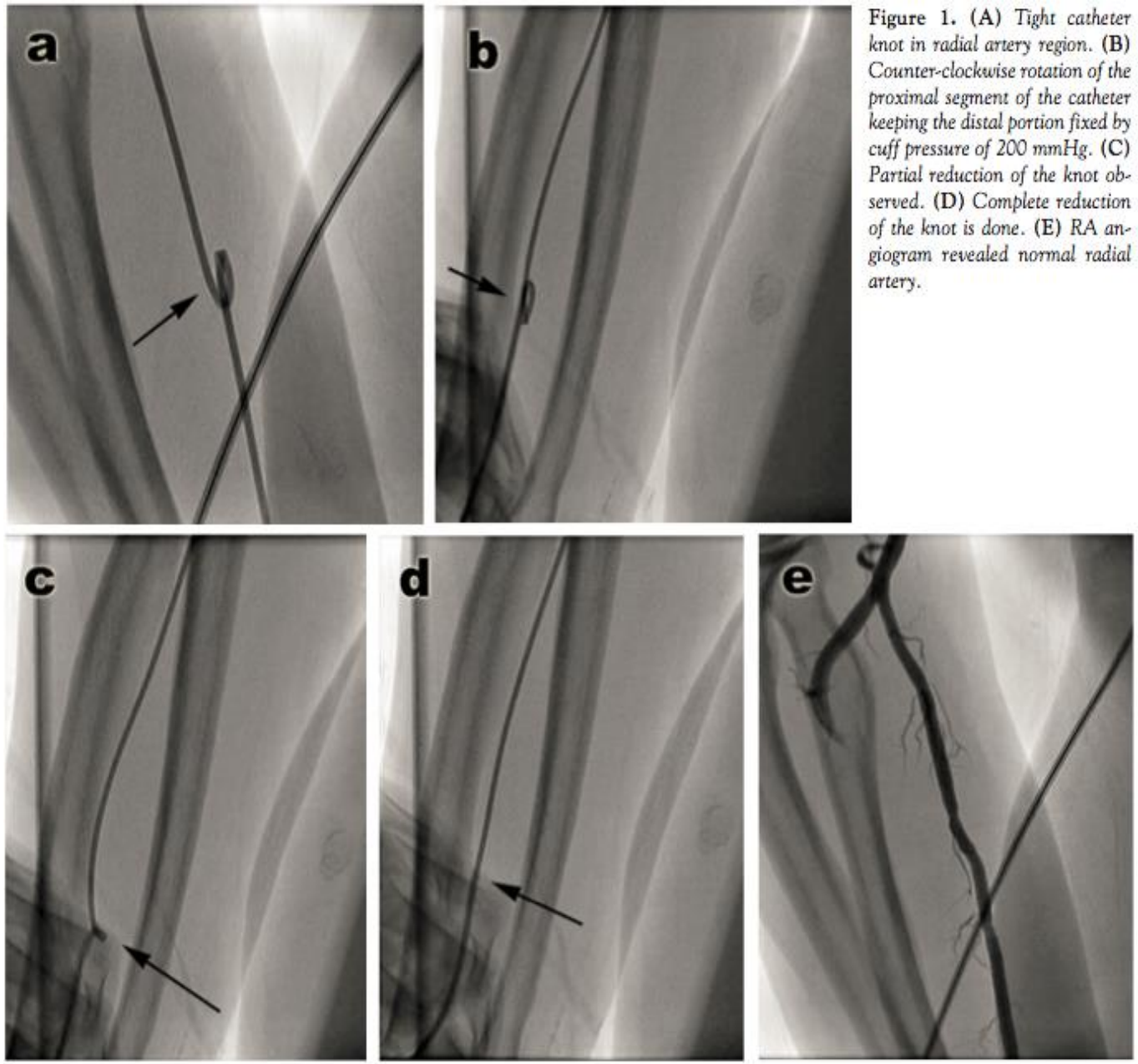
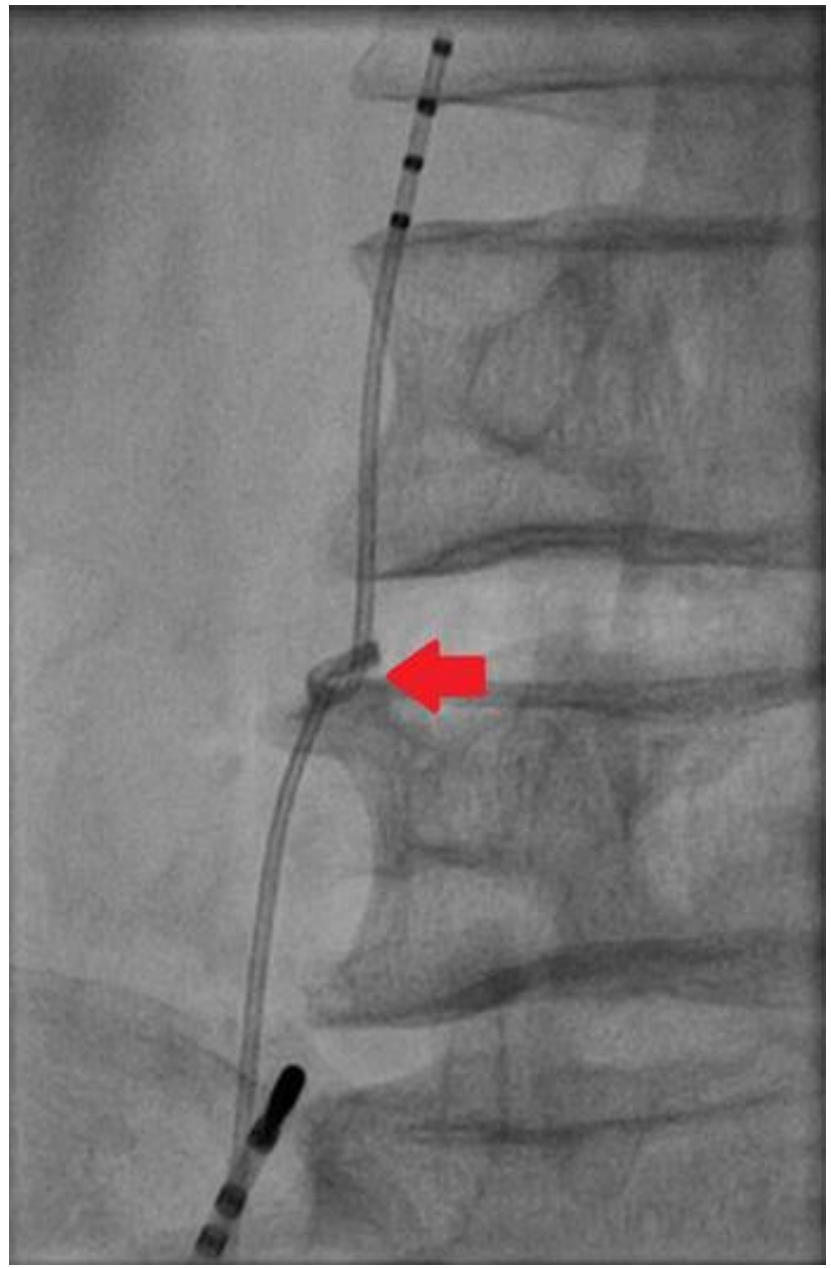
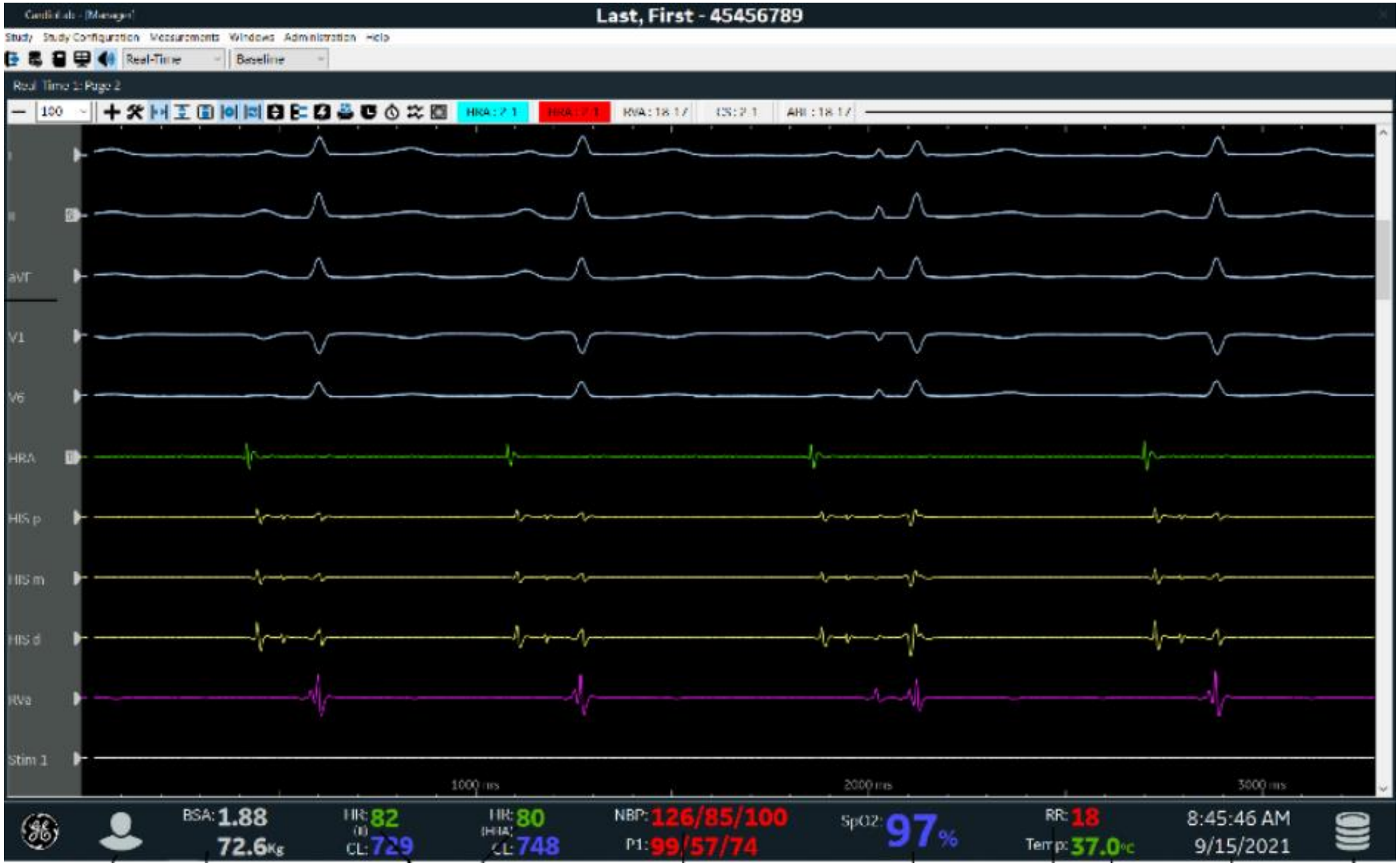
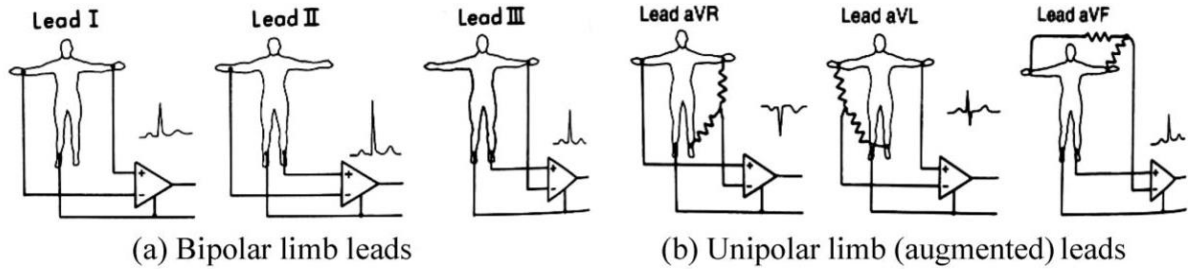


Figure 1. **(A)** *Tight catheter knot in radial artery region.* **(B)** *Counter-clockwise rotation of the proximal segment of the catheter keeping the distal portion fixed by cuff pressure of 200 mmHg.* **(C)** *Partial reduction of the knot observed.* **(D)** *Complete reduction of the knot is done.* **(E)** *RA angiogram revealed normal radial artery.*

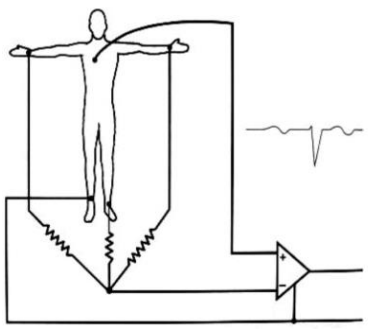



Last, First - 45456789
Study
Study Configuration
Measurements
Windows
Administration
Help
Real-Time
Baseline
Real Time 1: Page 2
100
HRA : 2.1
RVA : 18.1
IS : 2.1
AHI : 18.1
I
II
aVF
V1
V6
HRA
HIS p
HIS m
HIS d
RVa
Stim 1
1000 ms
2000 ms
3000 ms
BSA: 1.88
72.6Kg
HR: 82
CL: 729
HR: 80
CL: 748
NBP: 126/85/100
P1: 99/57/74
SpO2: 97%
RR: 18
Temp: 37.0°C
8:45:46 AM
9/15/2021

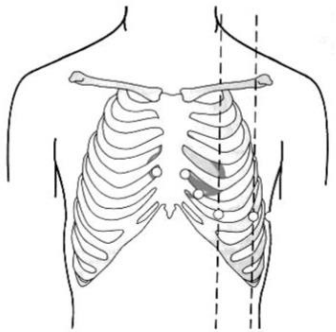
Electrogram recording and analyzing techniques



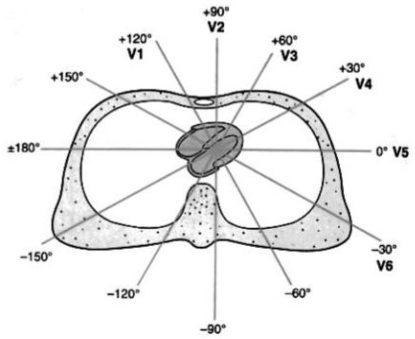
(a) Bipolar limb leads (b) Unipolar limb (augmented) leads



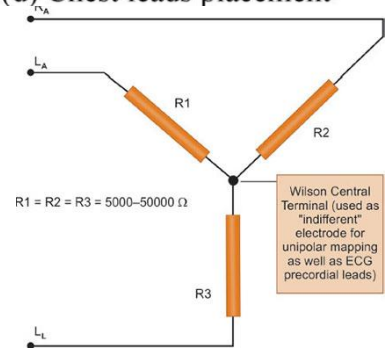
(c) Chest electrode

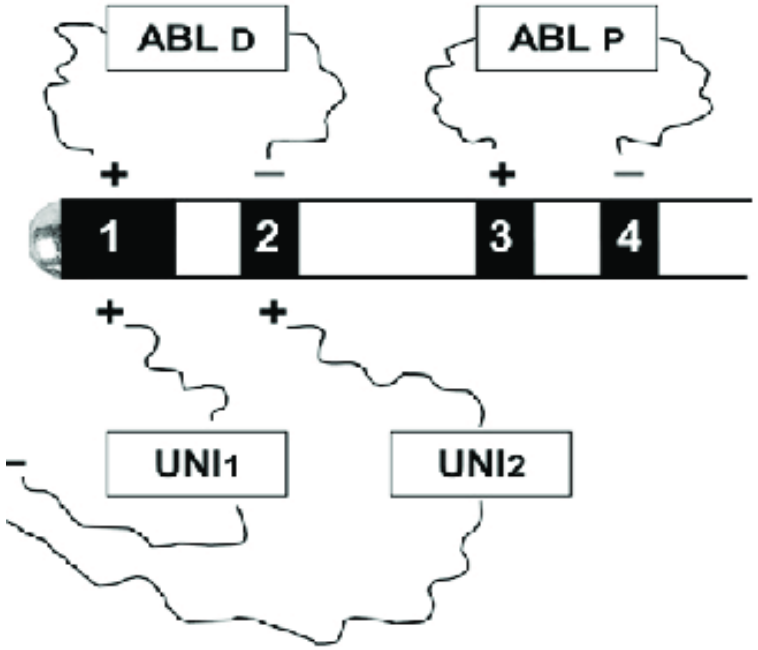


(d) Chest leads placement



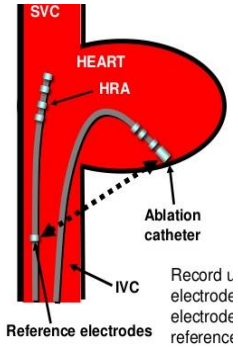
(e) Horizontal plane





Bipolar Recordings (30-500 Hz)

Unipolar Recordings (0.5-500 Hz)



Pacing Clin Electrophysiol. 2019;42:1503–1516

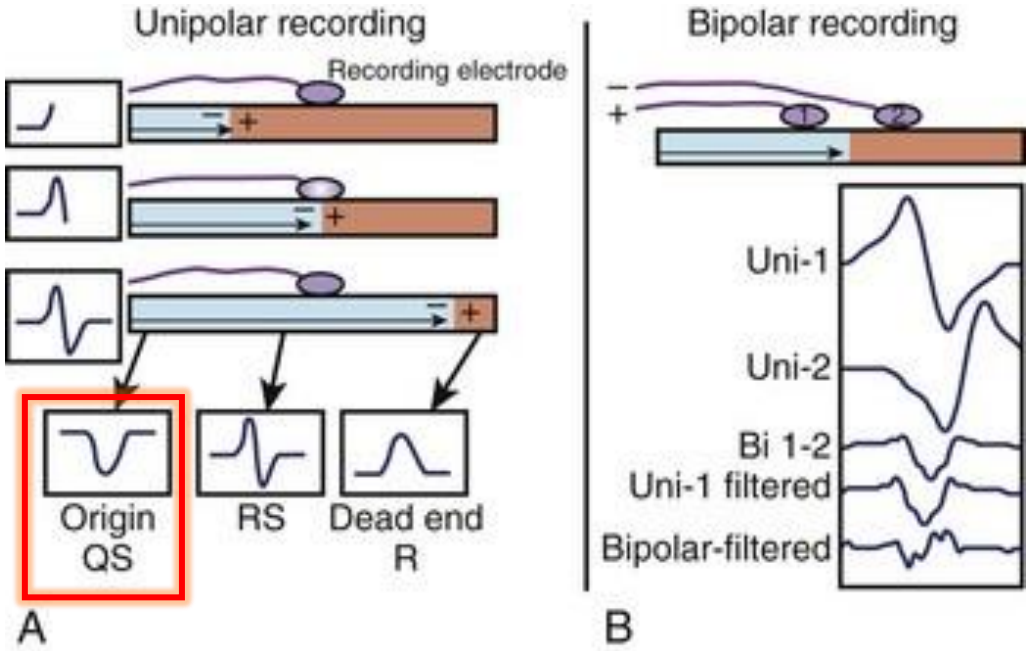
Unipolar vs Bipolar

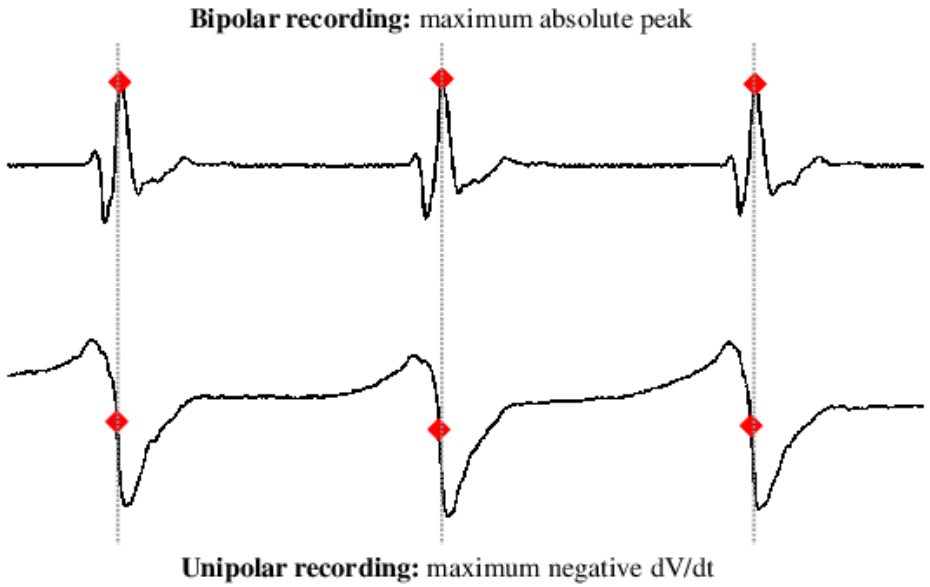
Unipolar recordings measure an amplified version of voltage at a single electrode and retain both near and far field signal components

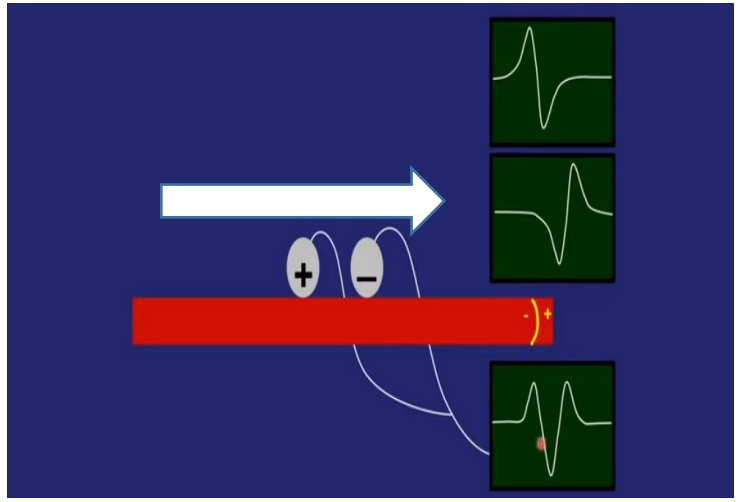
- Local + remote
- Catheter orientation independent
- Interference
- No directionality of propagation

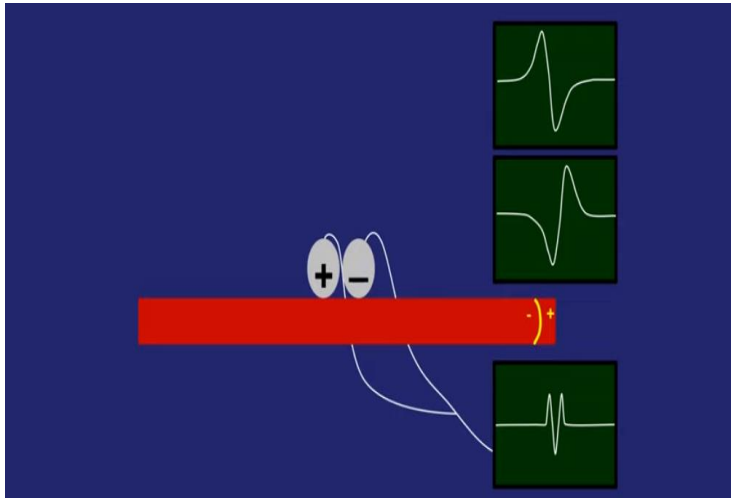
Bipolar recordings measure the amplified signal between two unipolar electrodes which reduces common-mode noise and far-field signal components

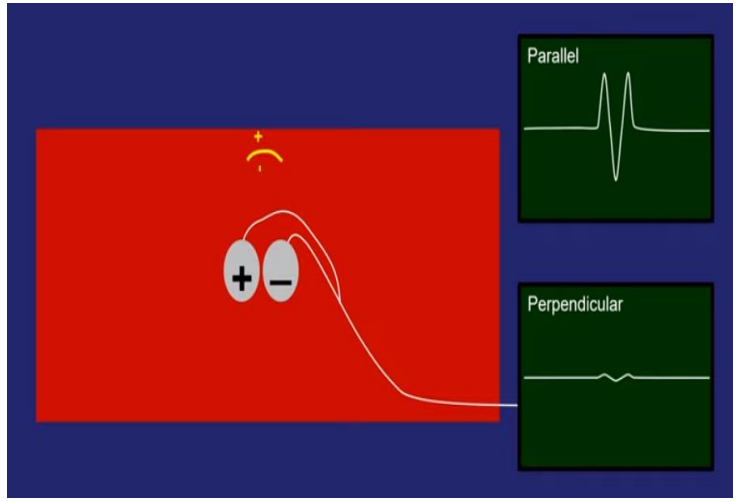
- Local
- Catheter orientation dependant
- Reduces interference
- Directionality of propagation

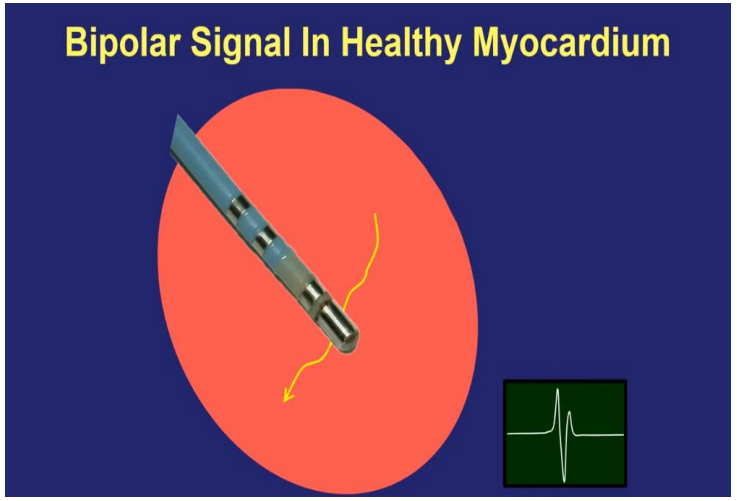


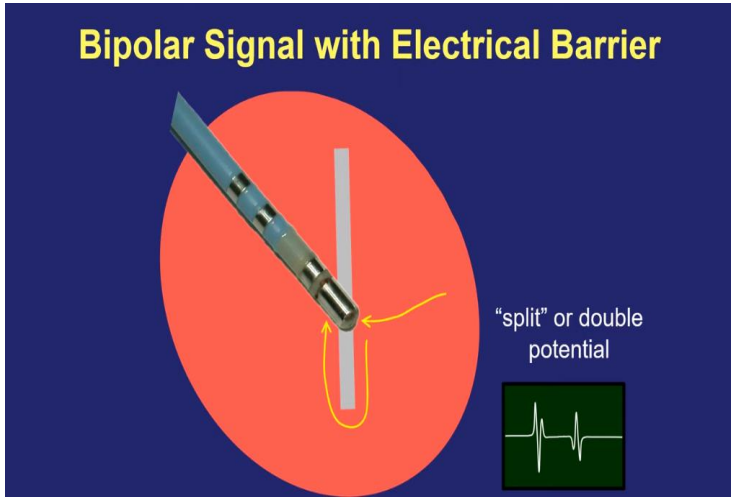


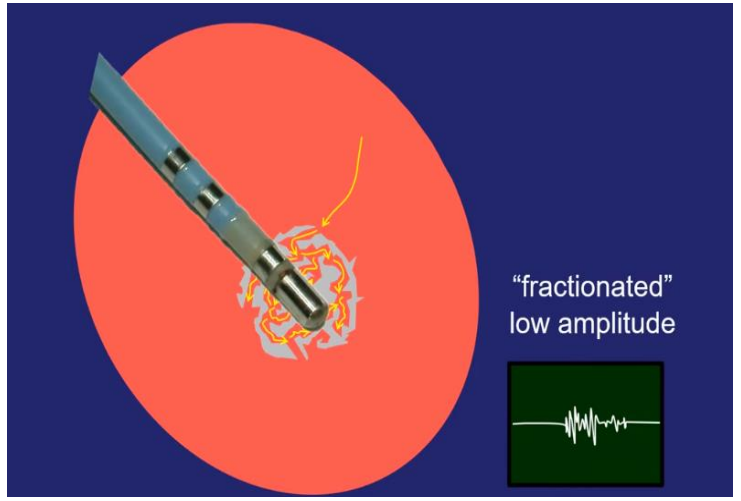


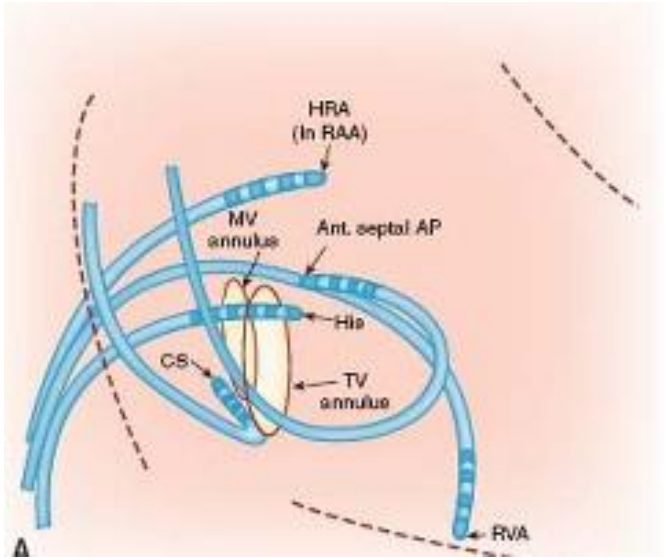


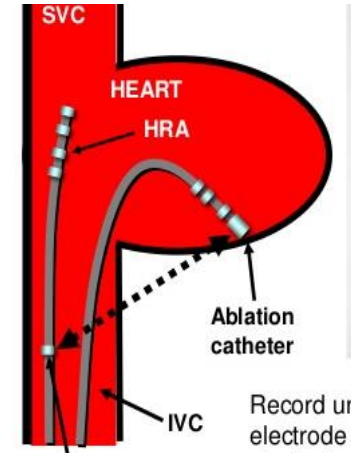

Parallel
Perpendicular

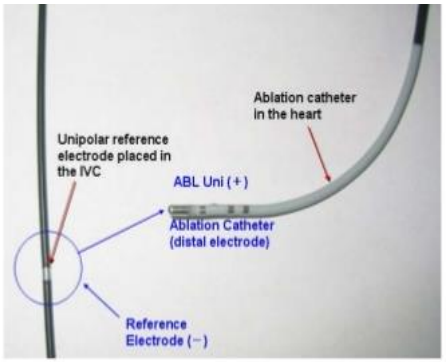

Bipolar Signal In Healthy Myocardium


Bipolar Signal with Electrical Barrier
"split" or double potential

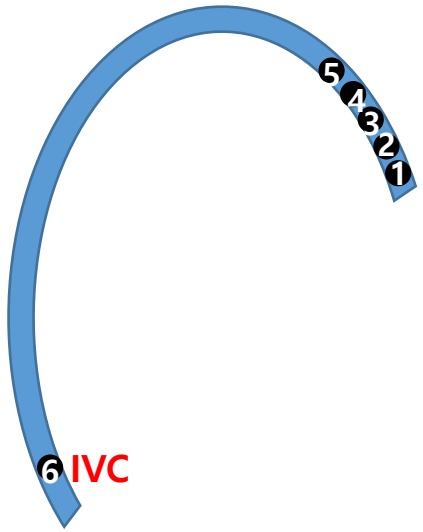

"fractionated" low amplitude

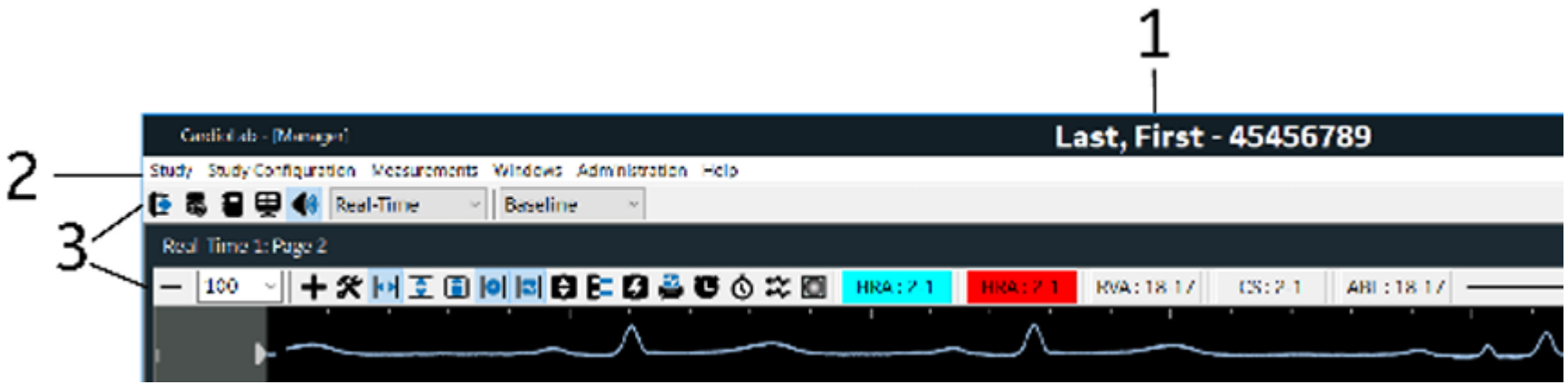






Record unipolar recording between the distal electrode of the ablation catheter (or the electrodes on the CS catheter) and one of the reference electrodes in the IVC





- Real Time
  - Clab II Plus Amplifier
    - ECG
    - Pressure
    - Catheter Block A
    - Catheter Block B
    - Catheter Block C
    - Catheter Block D
    - Catheter Block E
    - Catheter Block F
    - Catheter Block G
    - Stim
  - Input
    - Channel
  - Analog Out
  - Ablation
- Measurements
- Protocol List
- Activation Alignment
- Mapping

Display Settings | Hardware Settings

Scale: 1/16

Channel	Label	Type	Inputs +	Inputs -	Gain	Filter Settings High Pass	Filter Settings Low Pass	Notch Pass
49	ABL Sd	Bipolar	2	1	2500	30.00 Hz	150 Hz	On
50	ABL Sp	Bipolar	4	3	2500	30.00 Hz	150 Hz	On
51	HIS 1,2	Bipolar	6	5	2500	30.00 Hz	500 Hz	On
52	HIS 3,4	Bipolar	8	7	2500	30.00 Hz	500 Hz	On
53	HIS 5,6	Bipolar	10	9	2500	30.00 Hz	500 Hz	On
54	ABL d	Bipolar	18	17	2500	30.00 Hz	500 Hz	On
55	ABL p	Bipolar	20	19	2500	30.00 Hz	500 Hz	On
56	ABL Sd(A)	Unipolar - Aux. Ref.	1		500	0.50 Hz	150 Hz	On
57	ABL Sp(A)	Unipolar - Aux. Ref.	2		500	0.50 Hz	150 Hz	On
58	ABL Sd(W)	Unipolar - WCT	1		500	0.05 Hz	500 Hz	On
59	ABL Sm	Bipolar	3	2	2500	30.00 Hz	500 Hz	On
60		Not Used						
61		Not Used						
62		Not Used						
63		Not Used						
64		Not Used						

- Real Time
  - Clab II Plus Amplifier
    - ECG
    - Pressure
    - Catheter Block A
    - Catheter Block B
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    - Catheter Block D
    - Catheter Block E
    - Catheter Block F
    - Catheter Block G
    - Stim
  - Input
    - Channel
  - Analog Out
  - Ablation
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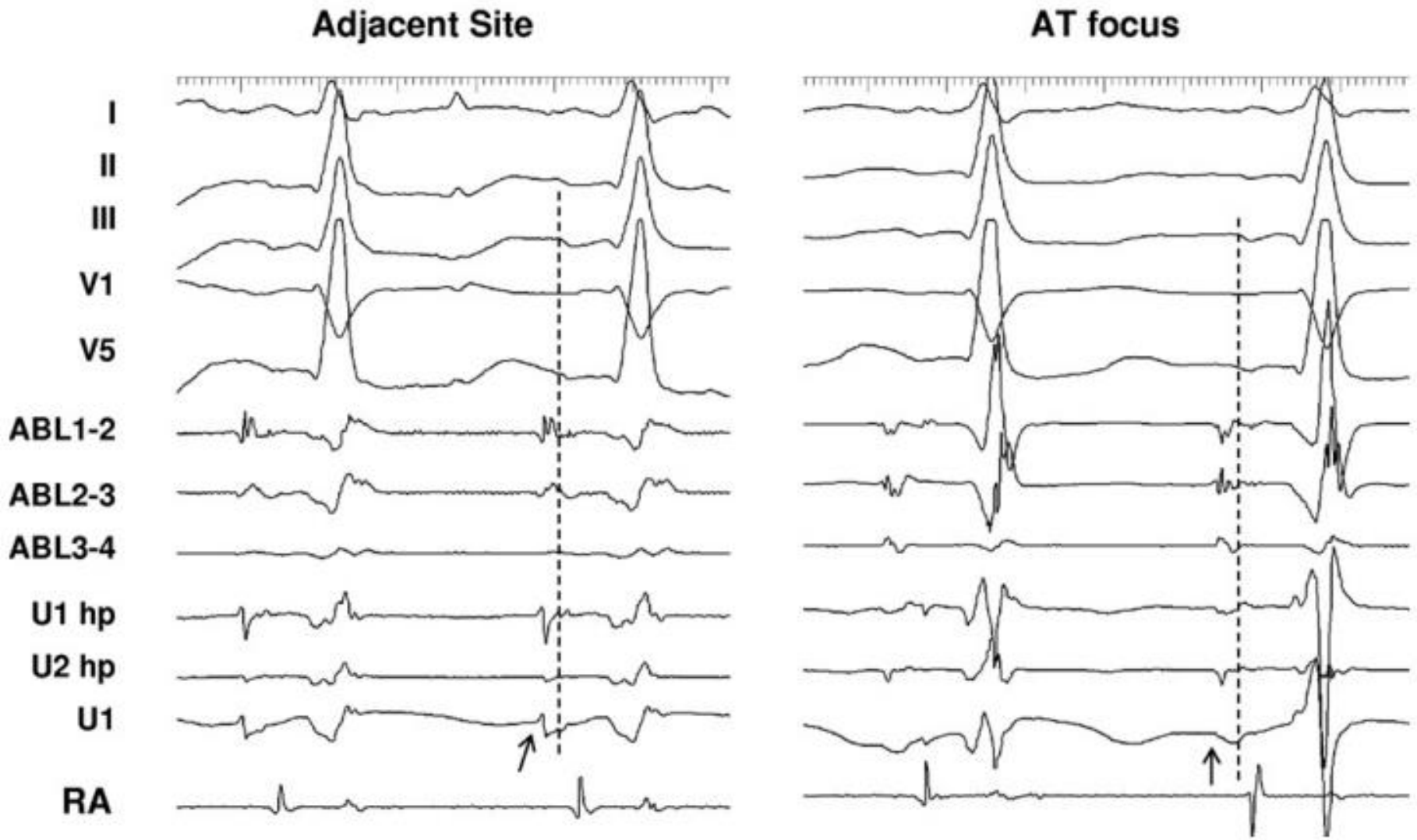
- Protocol List
- Activation Alignment
- Mapping

Display Settings | Hardware Settings

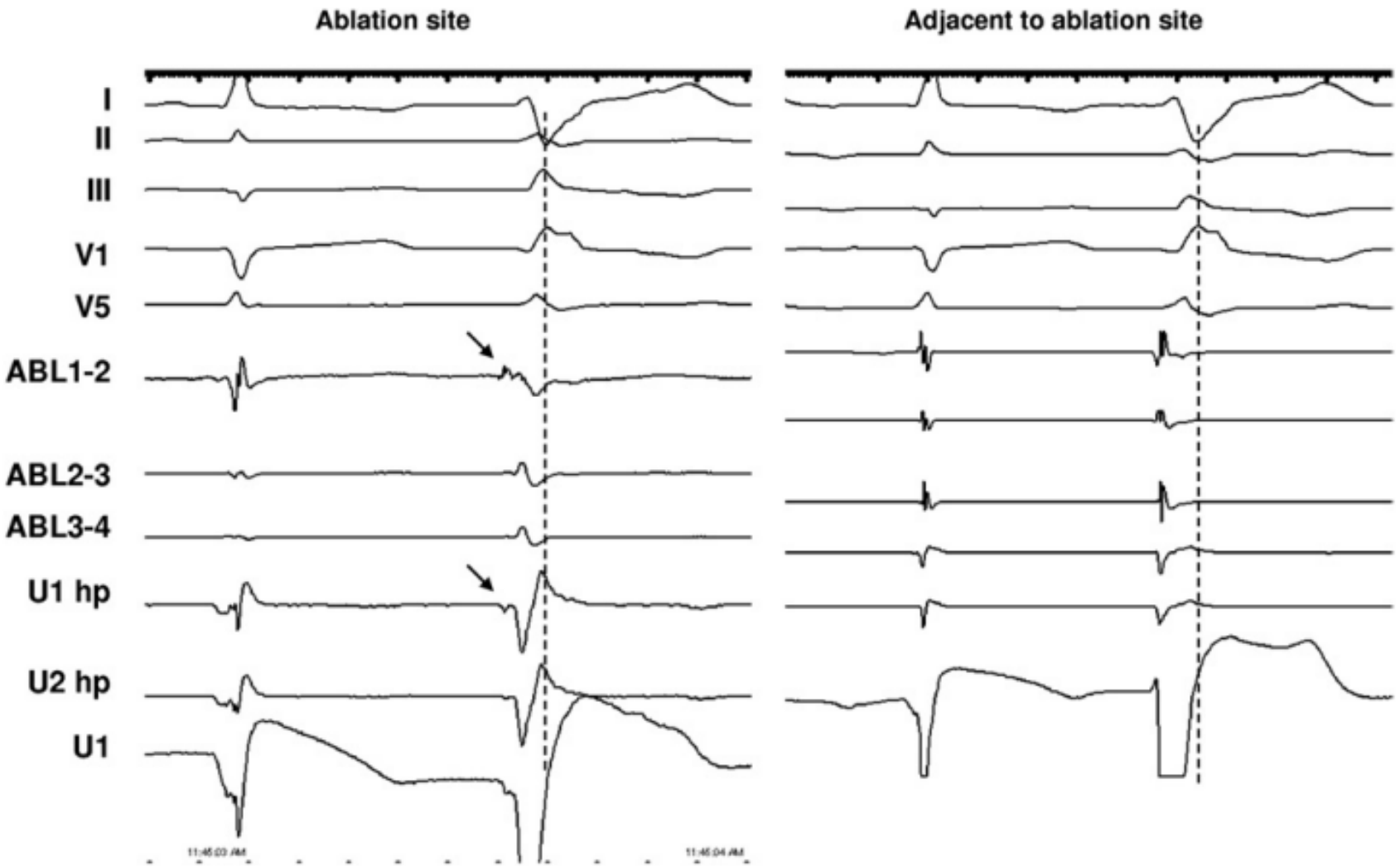
Scale: 1/16

Channel	Label	Type	Inputs +	Inputs -	Gain	Filter Settings High Pass	Filter Settings Low Pass	Notch Pass
33	CS 1,2	Bipolar	2	1	2500	30.00 Hz	500 Hz	On
34	CS 3,4	Bipolar	4	3	2500	30.00 Hz	500 Hz	On
35	CS 5,6	Bipolar	6	5	2500	30.00 Hz	500 Hz	On
36	CS 7,8	Bipolar	8	7	2500	30.00 Hz	500 Hz	On
37	CS 9,10	Bipolar	10	9	2500	30.00 Hz	500 Hz	On
38	ABL dist	Bipolar	18	17	2500	30.00 Hz	150 Hz	On
39	ABL prox	Bipolar	20	19	2500	30.00 Hz	150 Hz	On
40	Uni-d(A)	Unipolar - Aux. Ref.	17		500	0.50 Hz	150 Hz	On
41	ABL mid	Bipolar	19	18	2500	30.00 Hz	150 Hz	On
42	Not Used	Unipolar - Aux. R	18		1000	0.05 Hz	500 Hz	On
43		Not Used						
44		Bipolar						
45		Unipolar - WCT						
46		Unipolar - Aux. Ref. Ablate & Record Not Used						
47	Stim 3	Stim 3			50	30.00 Hz	500 Hz	On
48	Stim 4	Stim 4			50	30.00 Hz	500 Hz	On



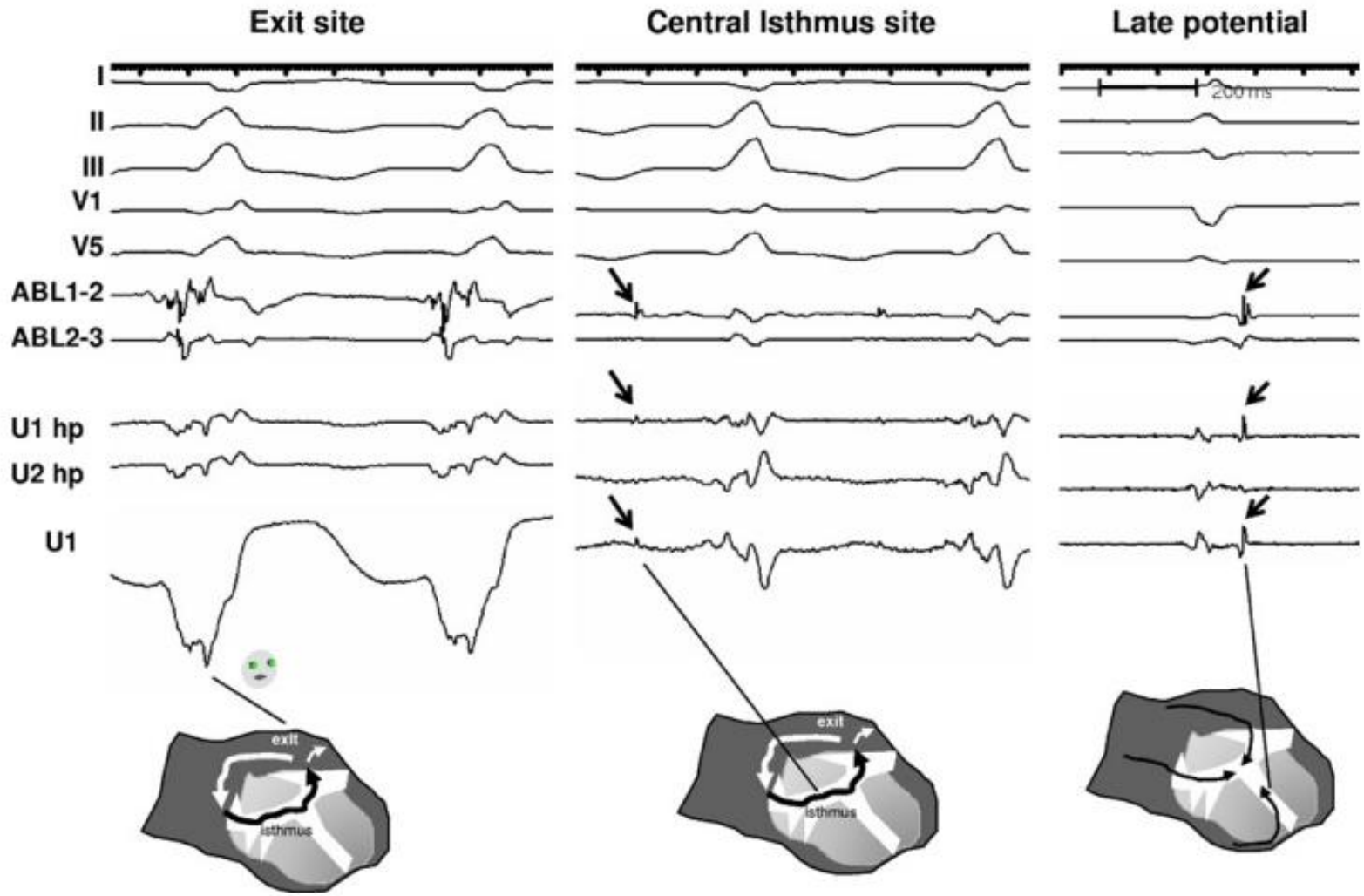
unipolar high-pass (30 Hz) filtered (U1 hp, U2 hp) and unipolar high-pass filtered at 0.5 Hz (U1) electrograms

Heart Rhythm, Vol 8, No 5, May 2011



Recordings of focal ventricular ectopy from the lateral papillary muscle. Shown from the top to bottom are ECG leads and recordings from the mapping catheter: bipolar (ABL1-2, ABL2-3, ABL3-4) and unipolar high-pass (30 Hz) filtered (U1 hp, U2 hp) and unipolar high-pass filtered at 0.5 Hz (U1) electrograms

Heart Rhythm, Vol 8, No 5, May 2011



Recordings from a patient with ventricular tachycardia (VT) due to an anterior wall myocardial infarction. Shown from top in each panel are ECG leads, bipolar recordings from the mapping catheter distal (ABL1-2) and middle (ABL 2-3) electrodes, unipolar 1 high-pass filtered at 30 Hz (U1 hp, U2 hp), and unipolar 1 signal with minimal high-pass filtering (U1)

Heart Rhythm, Vol 8, No 5, May 2011


ABL ON
aVF
V1
T10
T9
T8
T7
T6
T5
T4
T3
T2
T1
ABL d
ABL p
Stim 1
10:35:57 AM
10:35:58 AM
10:35:59 AM

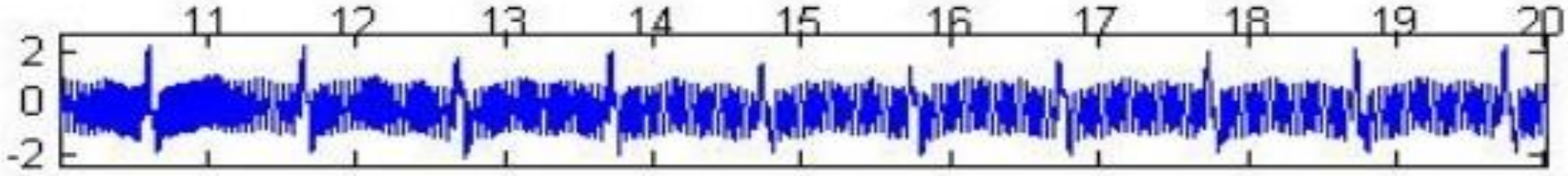

I
aVF
T10
T9
T8
T7
T6
T5
T4
T3
T2
T1
ABL d
ABL p
Stim 1
10:36:04 AM
10:36:05 AM
10:36:06 AM

Noise & Application of Filters

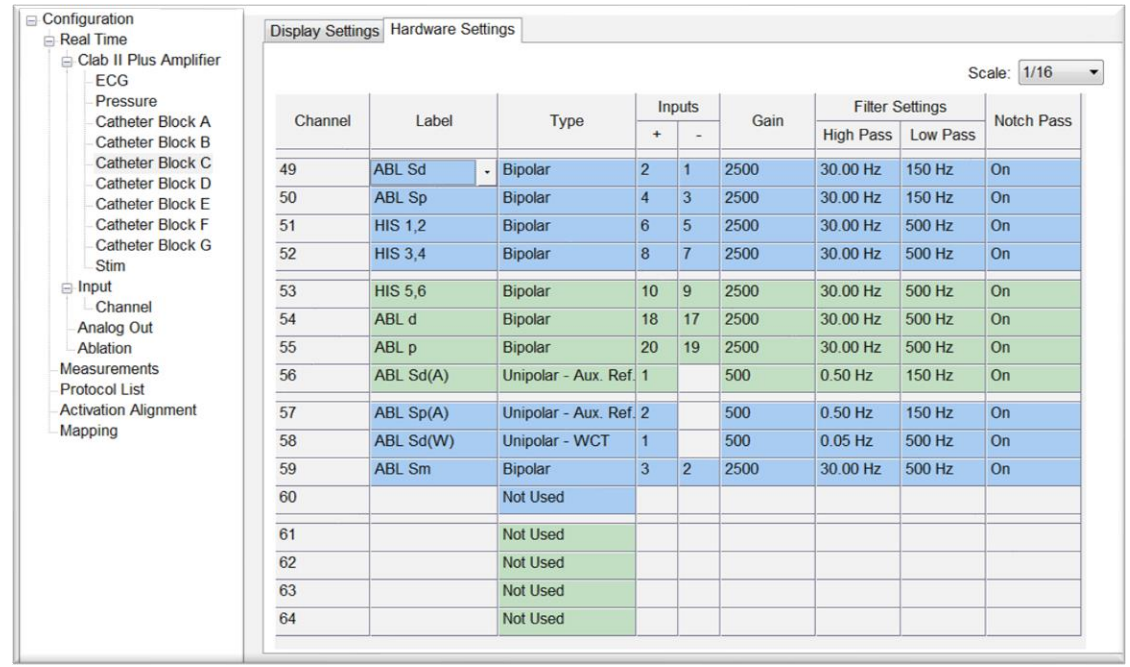
- The main sources of noise in ECG are
  - Low Frequency noise (Baseline Wander)
    - Muscle Tremor
    - Respiration

  - 50/60 Hz supply line noise

  - High Frequency noise
    - Other interference (i.e., radio frequency noise from other equipment)
    - Fluorescent lamps / bulbs
    - Any A/C Motor based equipment (pumps, Air Conditioners etc)



Signal Type	High Pass Filter	Low Pass Filter
Surface ECG	0.5Hz	100Hz
Intracardiac Bipolar	30Hz	300Hz
Intracardiac Unipolar	1-2Hz	300Hz
Unfiltered Unipolar	0.1Hz (or no high pass)	300Hz



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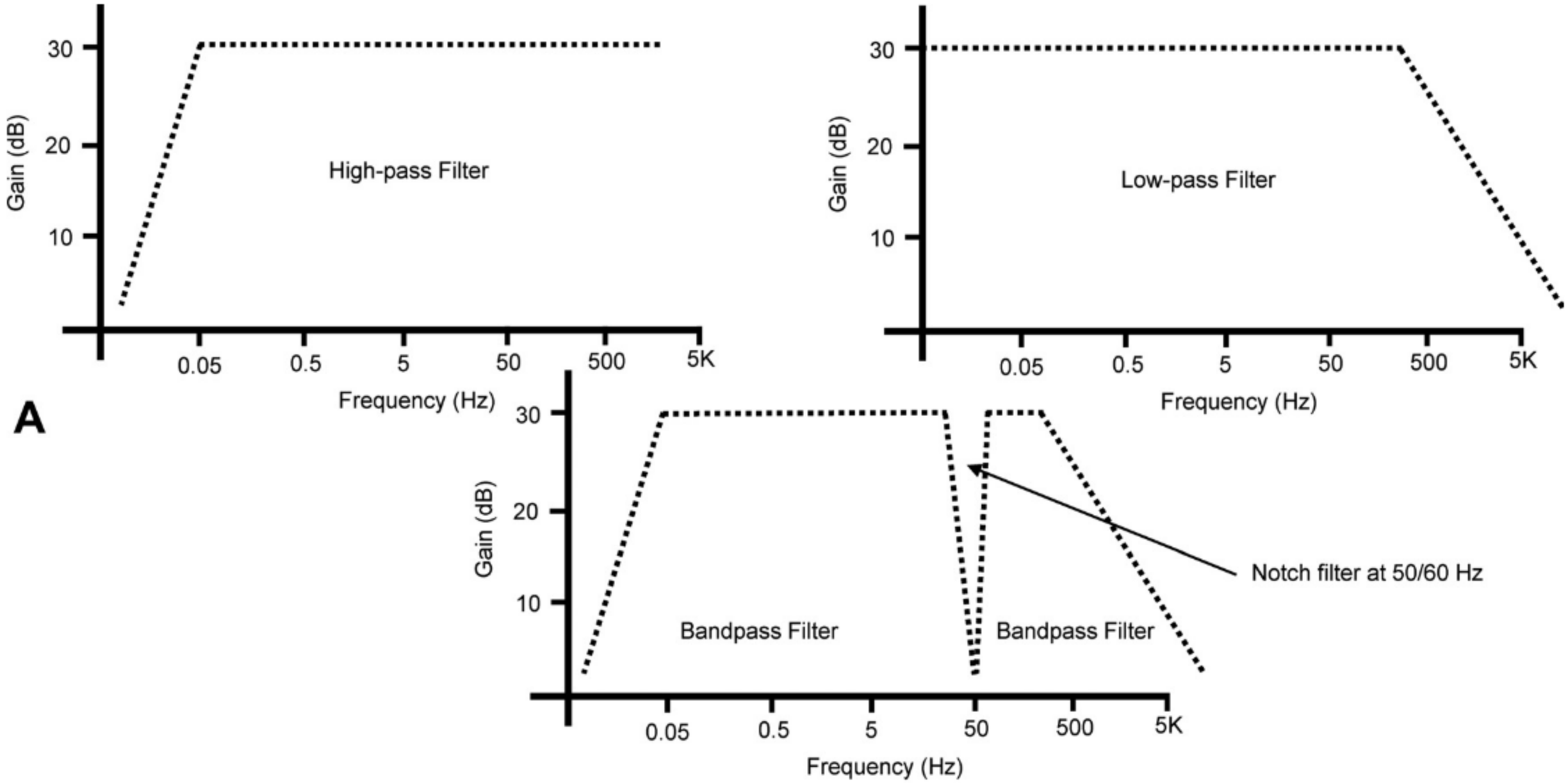
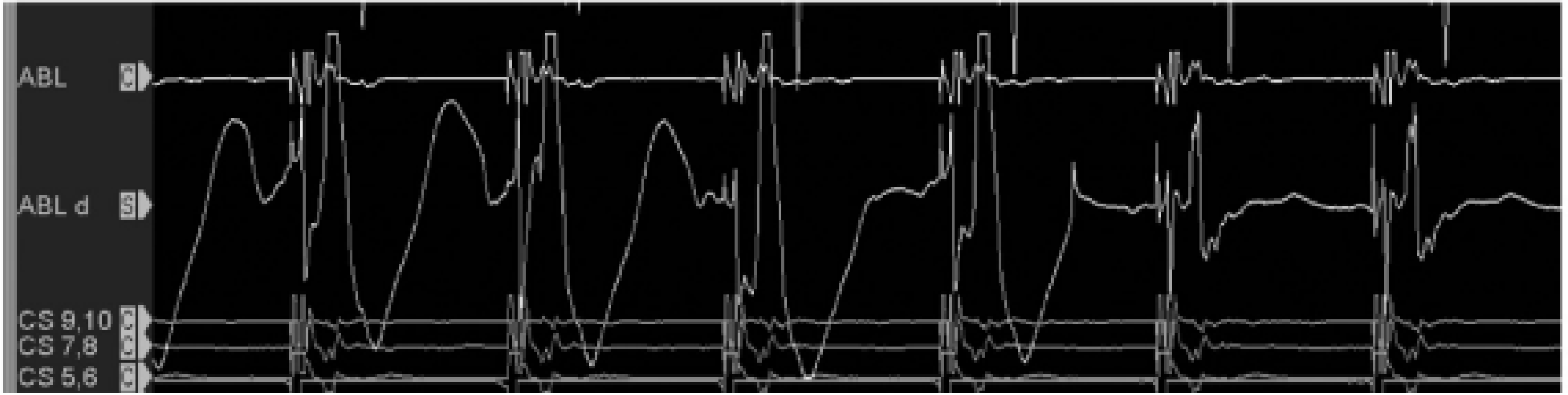
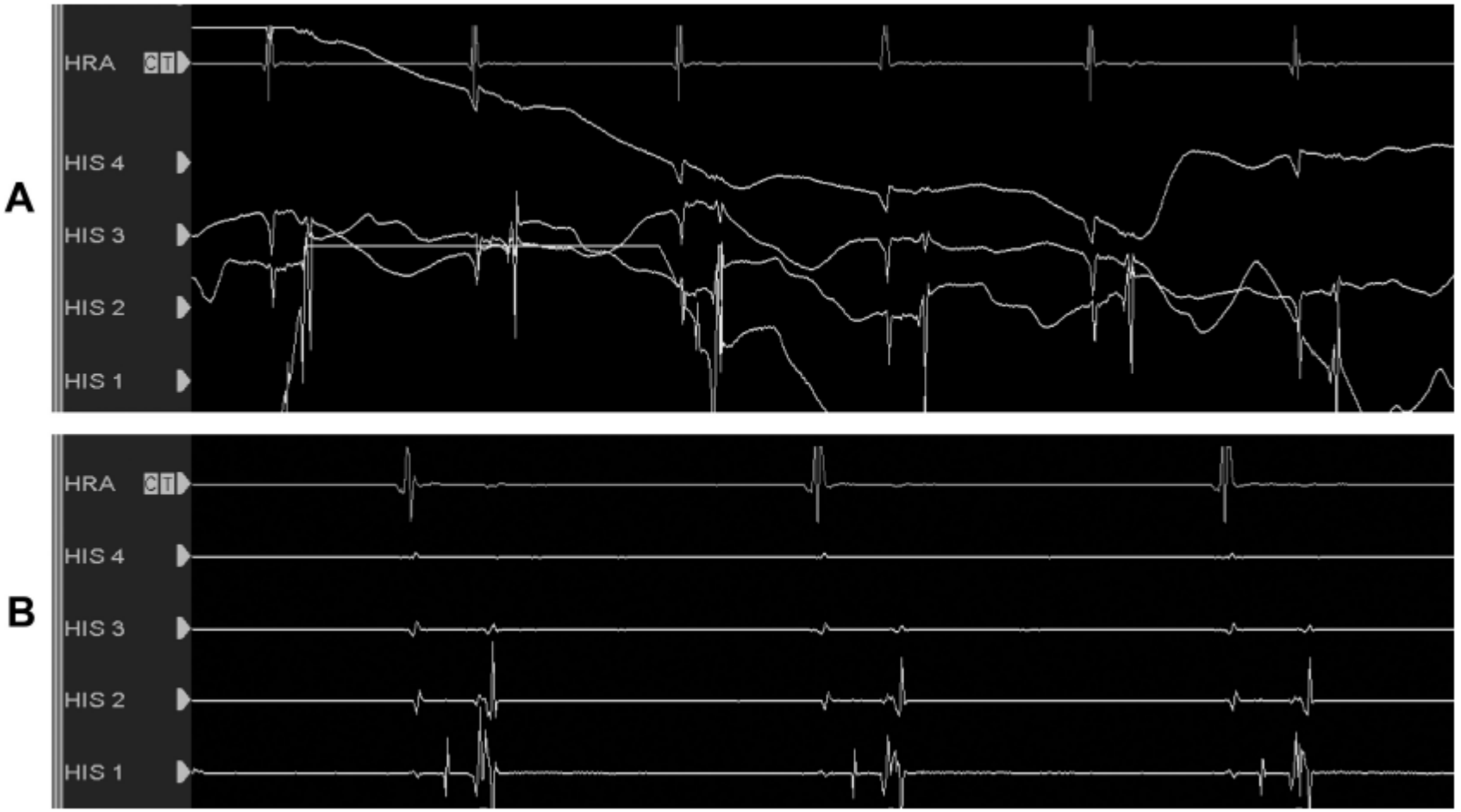
62		Not Used						
63		Not Used						
64		Not Used						



Circ Arrhythm Electrophysiol. 2011;4:965-973



Significant decrease in low-frequency signals on ABLd, with consequent improvement in signal quality during mapping of an antegrade accessory pathway with different high pass filter settings. The first 4 beats on ABLd use a high pass filter cutoff of 0.5 Hz and the remaining 2 beats use a (recommended) high pass filter cutoff of 30 Hz.

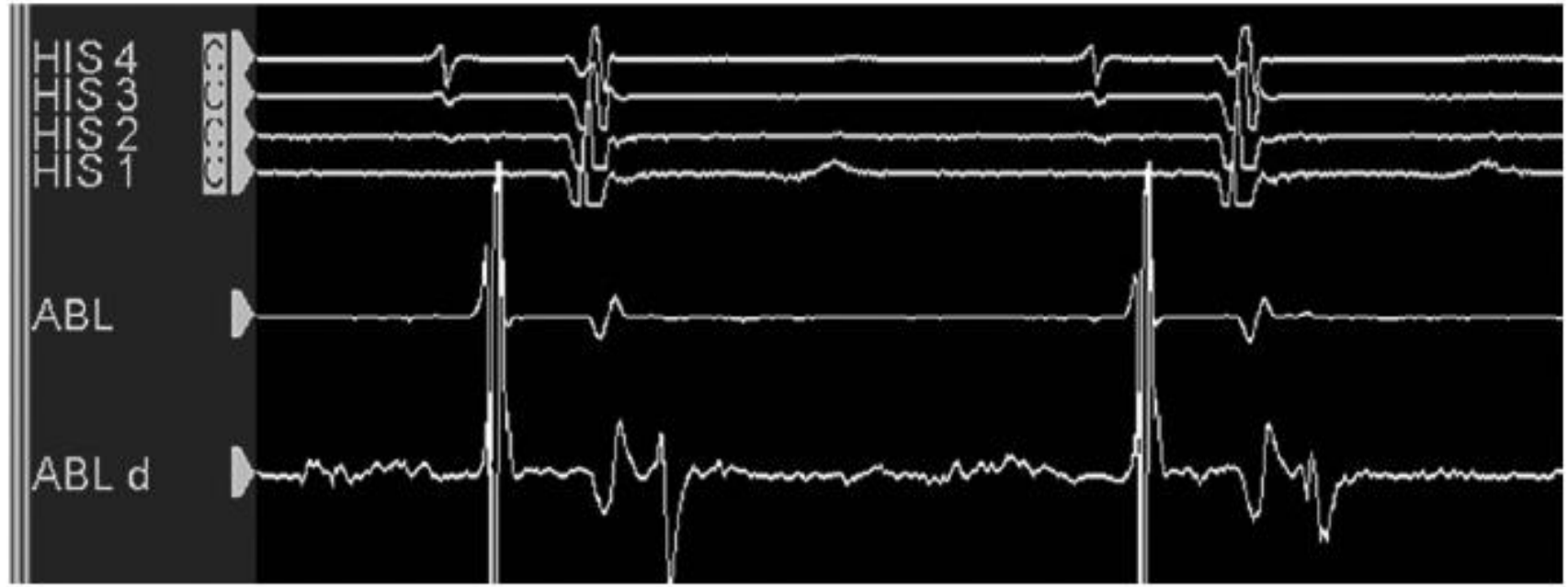


only 5 Hz at a heart rate of 300 beats per minute

Baseline drift reduction on the His electrodes with high-pass filter cutoff increased from 0.05 Hz (A) to 100 Hz

2 mL/minute irrigation rate

60 mL/minute irrigation rate



Take-Home Message

Acquiring and interpreting intracardiac electrograms in the noisy, unpredictable environment of the **modern EP laboratory is fraught with difficulties**; **however,** a combination of **good hardware** and **software design**, **careful management of noise sources** and **cabling** and **reasoned interpretation of the presented data** allow considerable **success during mapping and ablation of cardiac arrhythmias**