Conduction System Pacing: a Review

Jodie Hurwitz, MD, FHRS,FACC

North Texas Heart Center
Dallas, Texas, USA

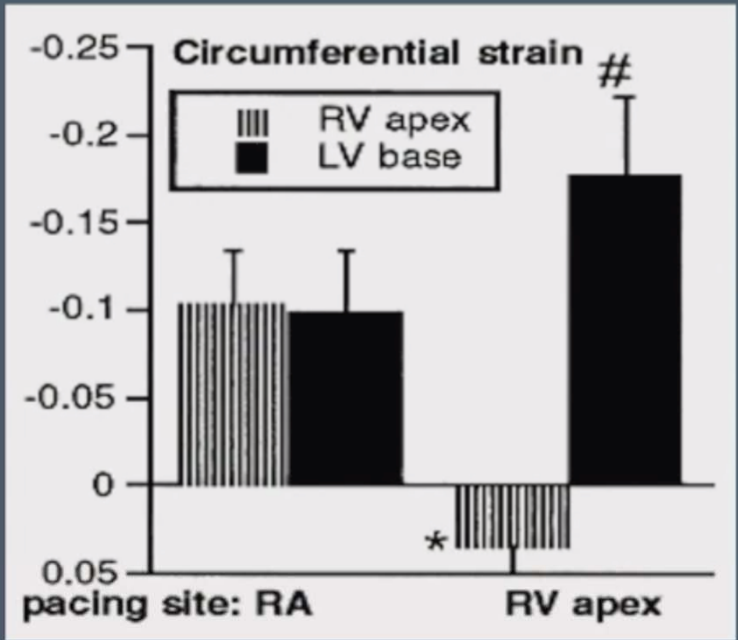
Korean Heart Rhythm Society

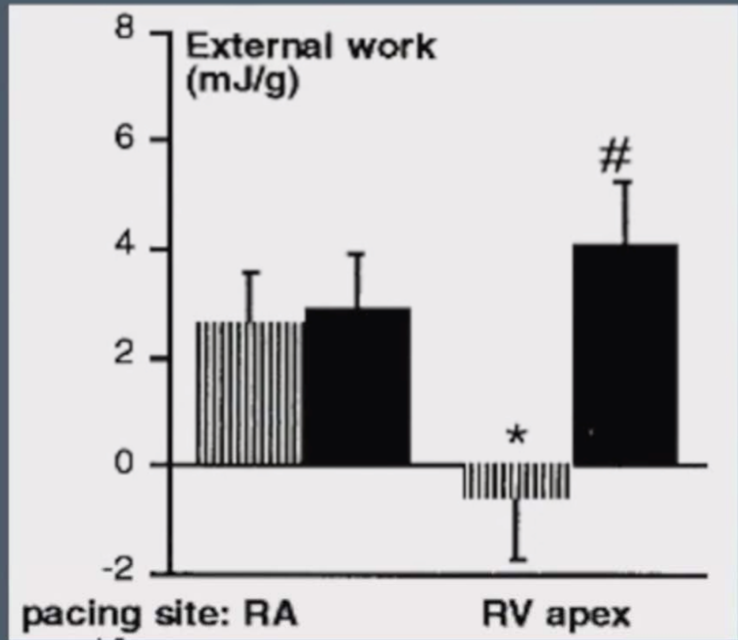
COI Disclosure

Jodie Hurwitz, MD

The authors have no financial conflicts of interest to disclose concerning the presentation

RV Apical Pacing Leads to Local Functional LV Abnormalities





Prinzen et al *J Am Col Cardiol* 1999;33 1735-42.

RV pacing: electrical and mechanical dys-synchrony

KHRS 2023

Historical ventricular pacing sites- any better?

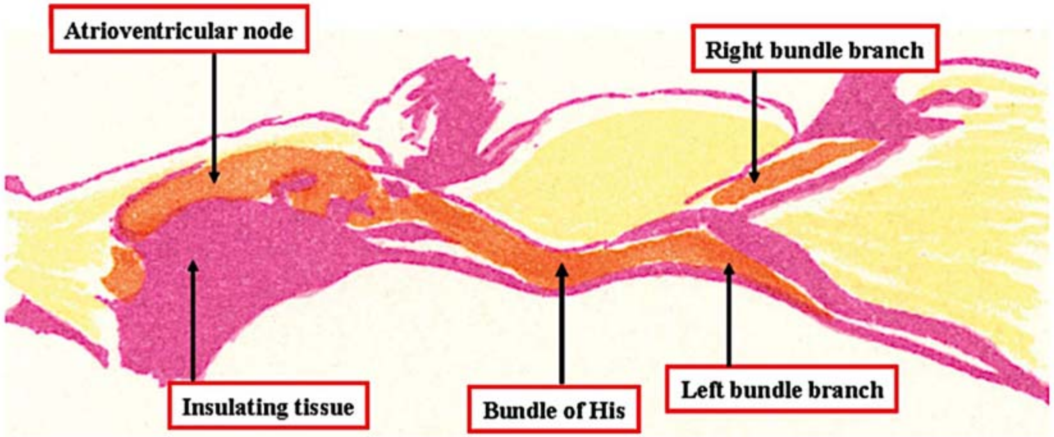
- Alternate RV site (septum/RVOT)
  - not superior to RVA pacing
- Cardiac resynchronization therapy (CRT)
  - still non physiological
    - activates ventricular myocardium and not the specialized conduction system

Conduction system pacing

- Narula and El-Sherif
  - Showed high amplitude His region pacing could resolve LBBB
    - (Circulation **1977**;56 (6): 996 and Circulation 1978; 57 (3): 473)
- Deshmukh et al
  - First demonstrated permanent His-bundle pacing in patients with dilated CM and AF (normal QRSd) with AVN ablation
    - (Circulation **2000**; 101:869)
  - Skill and time required were significant
  - Development of CRT occurred around same time
- Lustgarten
  - Showed His bundle region pacing could narrow QRS in pts with LBBB
    - (Heart Rhythm **2015**; 12(7): 1548)

Sunao Tawara: July 5, 1873 – January 19, 1952

"I intend, for the first time in medical history, to propose an integral and consistent explanation concerning the atrioventricular bundle and the Purkinje fibers"



Description 1906 by Sunao Tawara

- LB branches into 2 or 3 fascicles which further divide into finer branches + ultimately the Purkinje fibers
- Point stimulation at any branch will active this net-work

LBBP and LV septal pacing

- May be able to overcome distal conduction disease

Tawara 1906

Arrhythm Electrophysiol Rev 20 21 Apr; 10 (1) : 51

Verleg Gustav Fischer 1906

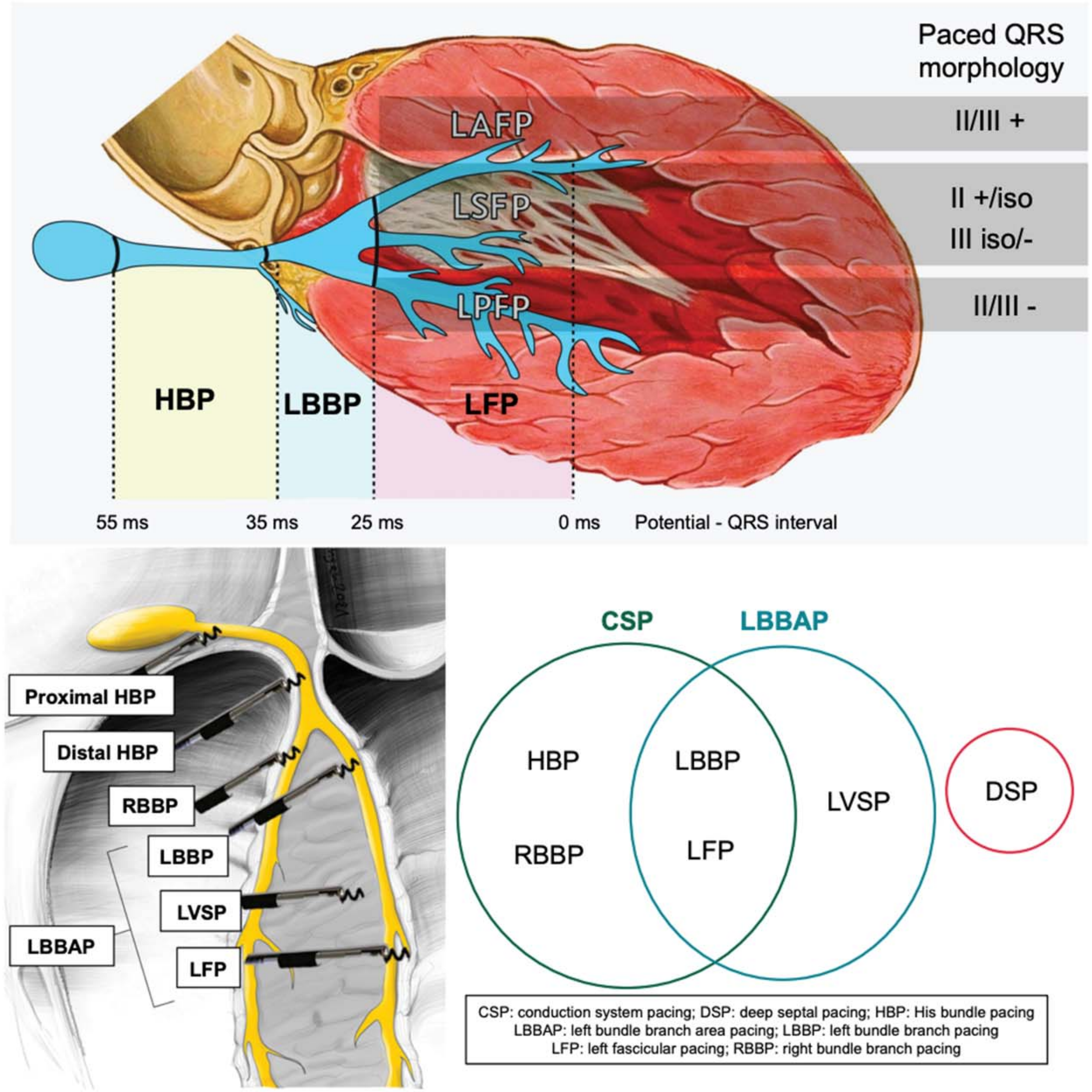


Figure 1 Synopsis of CSP and related pacing modalities. Modified with permission from Filip Plesinger and from Jastrzebski *et al.*[1]

Definition of conduction system pacing

direct activation of conduction system of the heart by pacing stimulus

Determination of level of capture:

anatomical position, paced QRS morphology and potential to QRS interval

<u>These all have limitations</u>

EP Europace volume 25, issue 4,April 2023; 1208; Burri H

His bundle pacing

- Small target
  - 1-2 mm wide + 10-20 mm long
- Encased in fibrous insulating sheath
- Pacing thresholds are generally high and increase with time
  - Loss of capture over time can occur
- Atrial oversensing
- Small R waves
- Can have delay distal to pacing site
- His-Synch study (only randomized prospective trial of His Synchronization)
  - success rate only 56%
- QRS cannot be normalized even with His bundle pacing in almost ½ of pts with LBBB

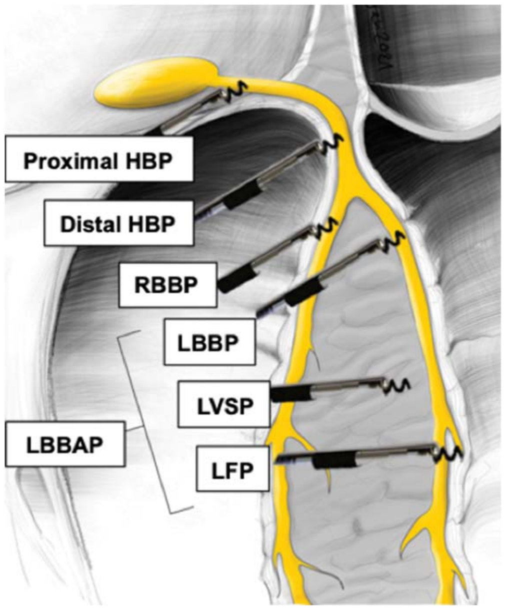
Heart Rhythm 2019; 16(12): 1797

Left bundle pacing

- Huang et al performed LB pacing in 2017
    - Medtronic 3830 lead screwed into RV septum and advanced until it paced LB with resolution of LB block
- Simpler than His bundle pacing
- Target is larger
- Pacing thresholds are low
- Pacing thresholds are stable over time
- R waves are good
- Lead position is stable over time

Can J Cardiol 2017; 33(12): 1736

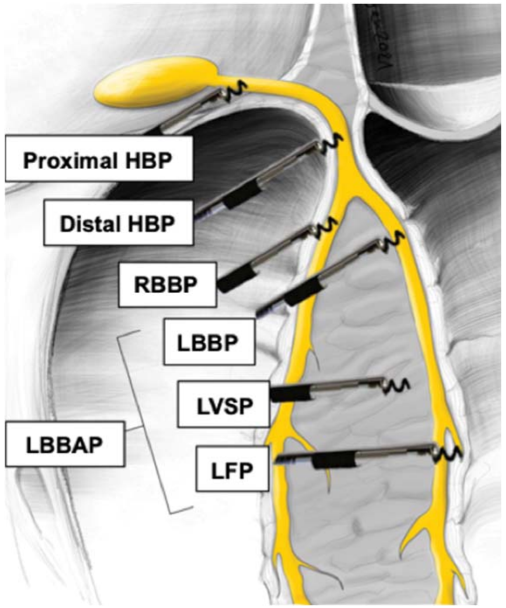
What is left bundle branch pacing?



- LBBAP
  - Left bundle area pacing
    - refers to LBBP or LVSP
  - LBBP, LFP, LVSP
    - Defined by anatomic position and terminal R wave V1 (not always present)
- LBBP
  - Pacing stimulus captures LB or it's branches ± capture of LV septal myocardium
    - Lead deep in IVS about 1-2 cm from distal Hs, LBB potential to QRS about 24-34ms, normal QRS axis, criteria for csp
- LVSP
  - Only LV septal myocardium is captured
  - Capture of left side of IVS without direct activation of left conduction system
  - Terminal R wave in V1, deep septal position in basal to mid-septum, absence of criteria for csp
    - Left sided conduction system may be engaged retrogradely

J Innov Cardiac Rhythm Manage.2022; 13(1):4829
EP Europace volume 25, issue 4,April 2023; 1208; Burri H

What is left bundle pacing?



- Left fascicular pacing
  - Capture of one of LBB fascicles
  - Short potential to QRS (<25ms), abnormal paced QRS axis, criteria for csp
    - Usually 2-4 cm distant from His
  - Wide target, minimal pseudo-delta wave during non-selective pacing-> narrow QRS
    - LAFP -> + leads II, II
    - Mid septal FP-> +/iso in II, iso/- III
    - LPFP-> - II,III

- Deep Septal Pacing
  - Lead is deep in septum but does not reach LV subendocardial area
  - No notches in left lateral leads, no terminal R wave V1

J Innov Cardiac Rhythm Manage.2022; 13(1):4829
EP Europace volume 25, issue 4,April 2023; 1208; Burri H

Lead name	SelectSecure 3830	Solia S	Ingevity	Tendril 2088TC
				
Manufacturer	Medtronic	Biotronik	Boston Scientific	Abbott
Design	Lumenless	Stylet-driven	Stylet-driven	Stylet-driven
Lead diameter (F)	4.1	5.6	5.7	5.8
Lead length (cm)	59/69/74	45/53/60	45/52/59	46/52/58/65/85/100
Cathode design	Electrical active helix	Electrical active helix	Electrical active helix	Electrical active helix
Tip electrode length (mm)	1.8	1.8	1.8	2.0
Tip electrode surface area (mm^2)	3.6	4.5	4.5	6.9
Tip to ring electrode spacing (mm)	9	10	10.7	10
Anode ring electrode surface area (mm^2)	16.9	17.4	20	16
Outer isolation	Polyurethane	Polyurethane/Silicone	Polyurethane (55D)	Optim™
Inner isolation	Silicone/ETE	Silicone	Silicone	Silicone
Steroid eluting	Beclomethasone Dipropionate	Dexamethasone Acetate	Dexamethasone Acetate	Dexamethasone Sodium Phosphate

26:52 / 1:30:29

Adapted from De Pooter et al. (2022) Front Cardiovasc Med.

023

How to position lead:

- **<u>12 LEAD ECG</u>**
- Place 1-1.5 cm below His along imaginary line from distal HB to RVA in RAO 30 degrees
- Looking for initial W pattern in V1
- Tall R wave in lead II
- RS in lead III
- Discordant QRS complexes in avR and avL
- As lead is screwed into septum:
  - lead V1 will develop R wave, current of injury on lead EGM
- DON'T want:
  - drop in pacing impedance of > 200 ohms or reduction in sensed R wave

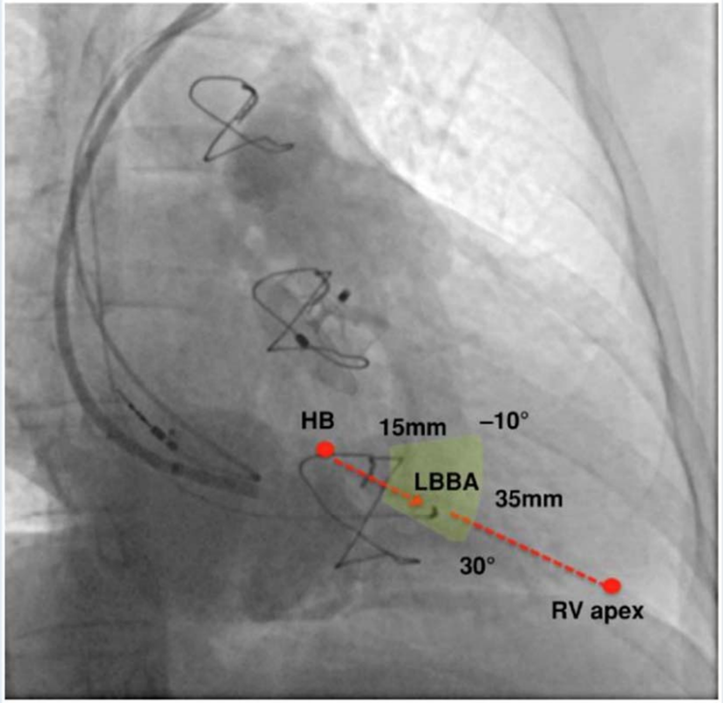


Figure 3 Insertion site for LBBA pacing. In a 30° RAO view, contrast is injected through a sheath delineating right atrial and ventricular anatomy as well as tricuspid valve leaflets. The summit of the tricuspid annulus indicates the approximate His bundle position. The red arrow indicates an imaginary line that connects the tricuspid annulus summit/ His bundle with the RV apex, which serves as a guide for placing the lead. Successful pacing sites can be localized within a sector (indicated in yellow) located 15–35 mm away from the tricuspid annulus summit and at an angle of −10° to 30°, as described by Liu *et al.*[16]

His bundle recording and tagged as reference in RAO 20-30
Takes extra time

Can use TV summit as anatomic marker
advance sheath 15-20 mm towards RV apex with lead within sheath, counter clock torque on sheath to reach RV basal to mid septum

Evaluate unipolar configuration on PSA
Paced QRS: W pattern with a notch in V1 and discordant QRS in II (~+) and III (~-)

Placement of the LBBP lead > 16mm or > 19 mm from TA has been associated with less TV regurgitation

EP Europace volume 25, issue 4,April 2023
Page 1208; Burri H
Heart rhythm 2022;19: 1202;
Heart rhythm 023; 20;217

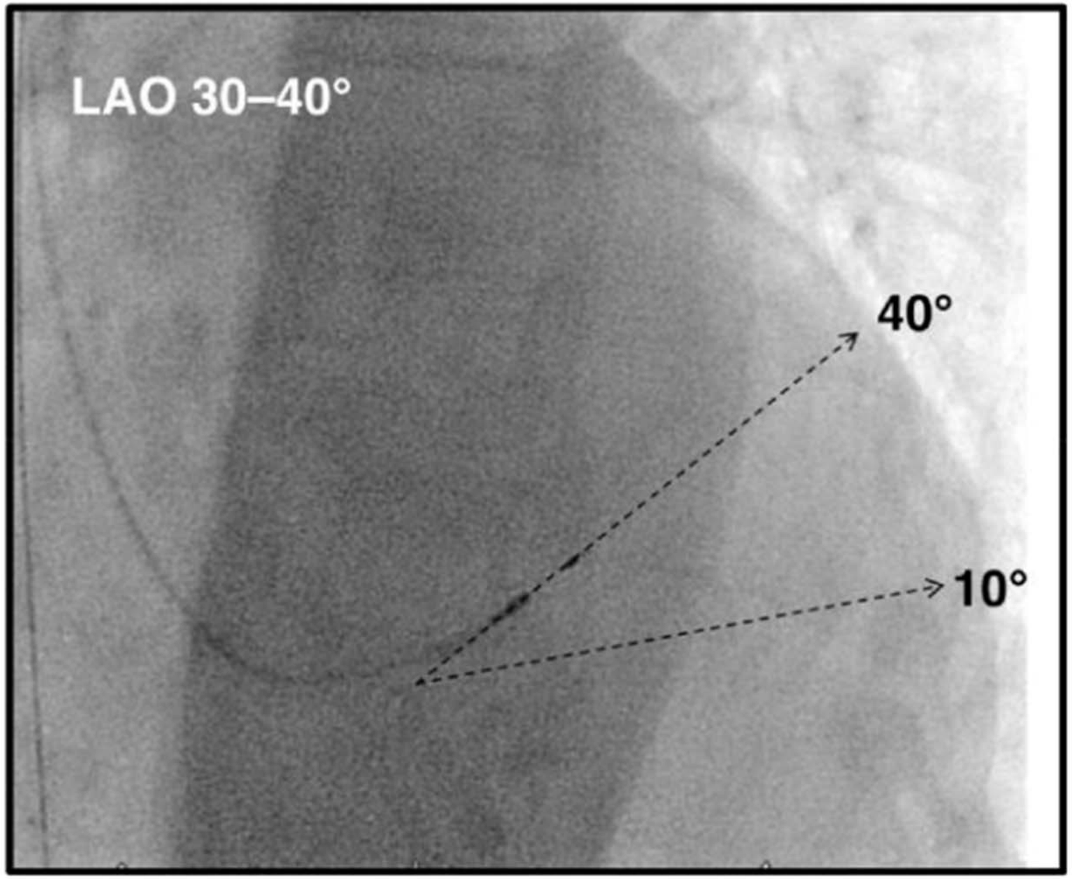


Figure 4 Left panel: LAO view for orienting the lead 10–40° (most often 20–30°) with respect to the horizontal plane for perpendicular septal penetration.

Position delivery catheter perpendicular to IVS with slight counter-clockwise rotation

- 30-40 degree LAO
- want lead oriented 10-40 degrees superior to horizontal plane

- Rapidly rotate lead (lumenless)
  - Assess behavior of lead during rotations
    - Don't want drill effect, or strong torque build up on lead
    - want screwdriver effect

EP Europace volume 25, issue 4,April 2023
Page 1208; Burri H

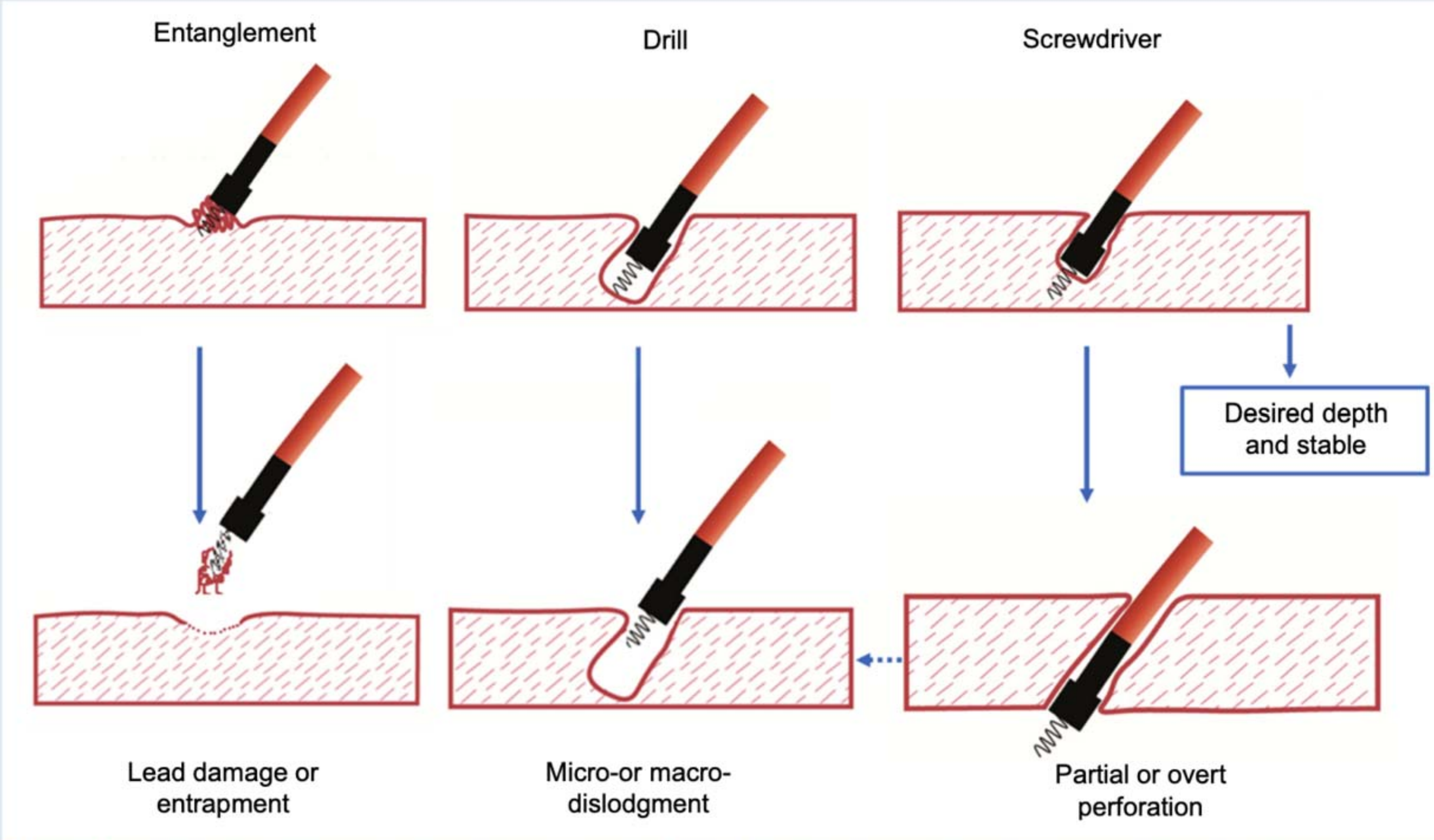
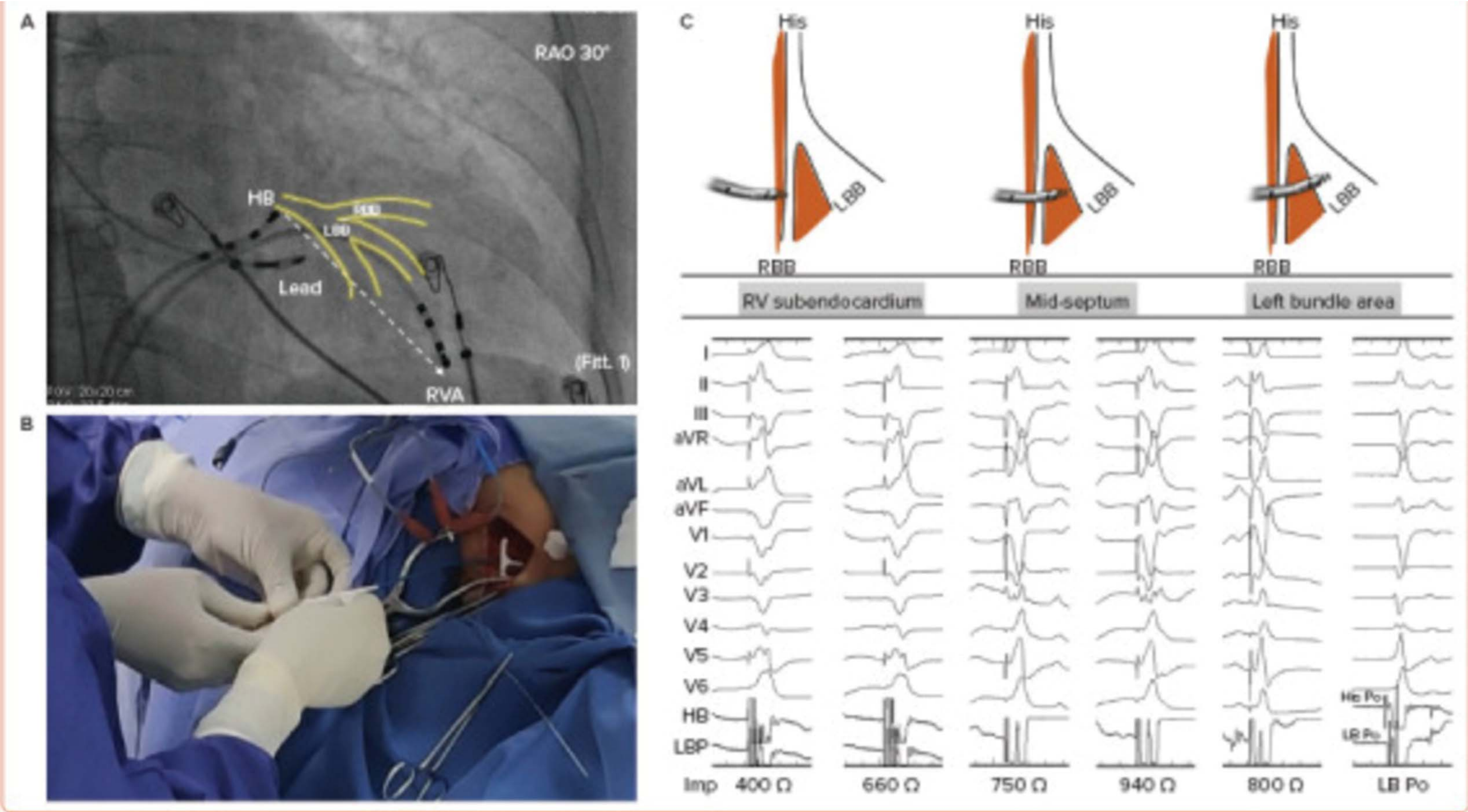


Figure 5 Lead behaviour during penetration of the septum with LBBAP. Both drill and screwdriver effects can result in perforation.

KHRS 2023



Card Fail rev 2021 Mar;7:e13

Confirming Left Bundle branch area capture

- **This can be hard**
- Transition in QRS morphology: GOLD STANDARD

- Unipolar pacing to confirm capture (avoids anodal capture)
  - Decrease from high output (5-10V) to
  - demonstrate transition from capture of LBB and septal myocardium (ns) to capture of either only LBB or septum (s)
  - If no change: nonconclusive!
    - could be that capture of both is equal

Positioning lead

- ways to look at lead depth
  - watch rotation
  - unipolar paced QRS morphology
  - QRS should become narrower and lose notches
    - Qr, qR, rsR', R can appear in V1 and V6RWPT progressively shortens

- Can have fixation beats (pvcs) –
  - morphology of these correspond to actual depth of lead tip

- Unipolar pacing impedance
  - Usually increases then falls
  - Don't want values of <500 ohms or drop by 200 ohms

Positioning leads

- Myocardial COI **
  - Sensed COI decreases as lead reaches LV subendocardium
  - High COI assures ability for possibly more lead rotation
  - Drop in COI: be careful
  - Test with unipolar sensing:
    - If fall/disappear with bipolar sensing has no pathological significance

- If you see LBB/fascicular potentials:
  - subendocardium has been reached:
    - don’t rotate any more
- Contrast injection to be sure you are against the septum

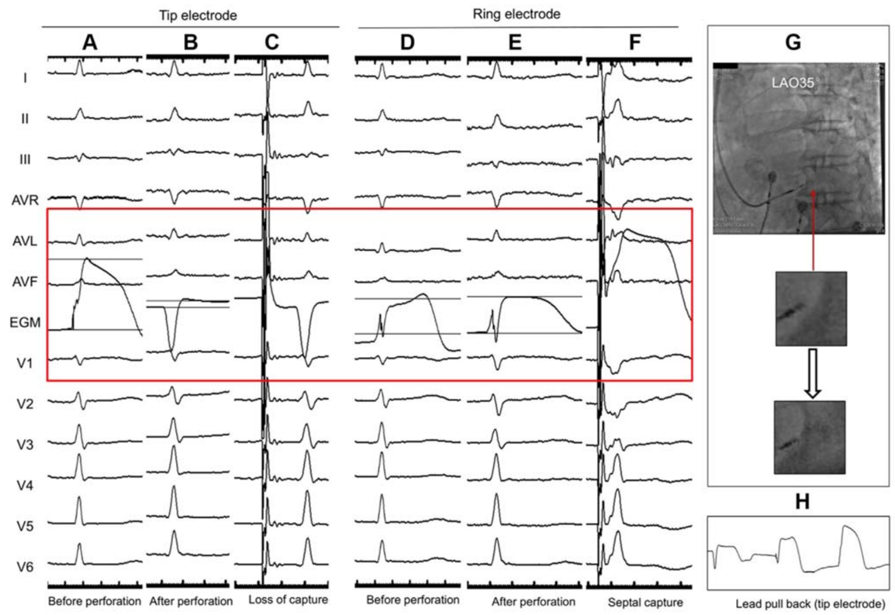
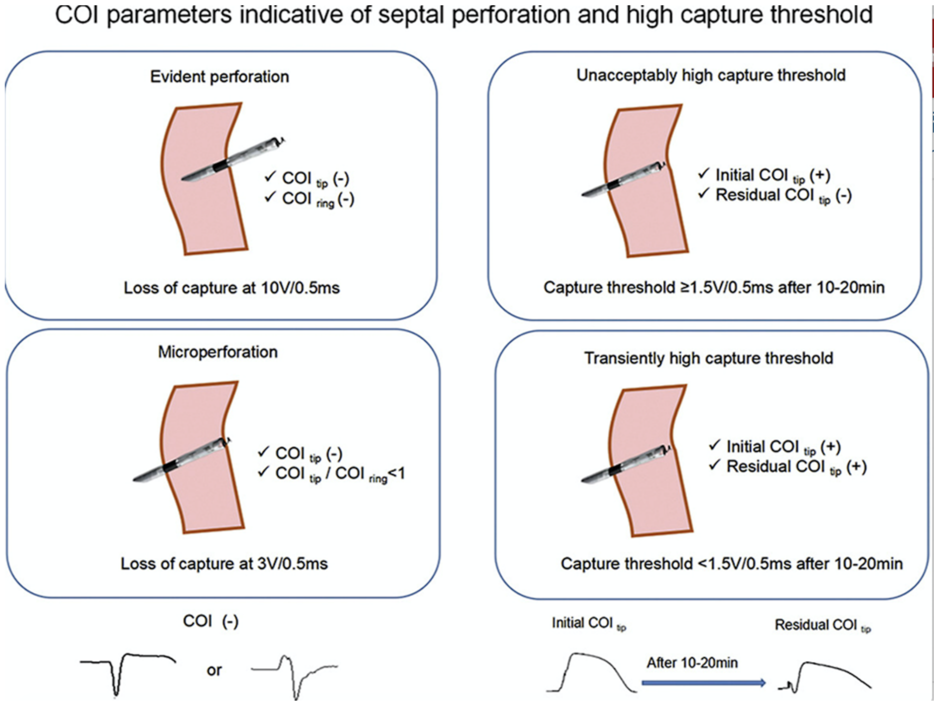


Figure 3 Dynamic changes on the intracardiac electrogram during LBBP lead perforation. **A:** Distinct COI_{tip} during intrinsic rhythm before perforation. **B and C:** Microperforation after 1 bonus rotation, showing a lack of COI_{tip} and loss of capture at 3.0 V/0.5 ms. **D–F:** Significant COI before and after perforation along with myocardial capture at 3.0 V/0.5 ms on the ring electrode. **G:** Angiography at LAO35° showed a minor amount of contrast being injected from the sheath into the left ventricular chamber. **H:** Gradually increase in COI_{tip} when pulling back the lead. COI = current of injury; COI_{tip} = current of injury recorded on the tip electrode; EGM = electrogram; LAO35° = 35° left anterior oblique; LBBP = left bundle branch pacing.

Heart Rhythm 2022;19:1281

Heart Rhythm 2022;19:1281

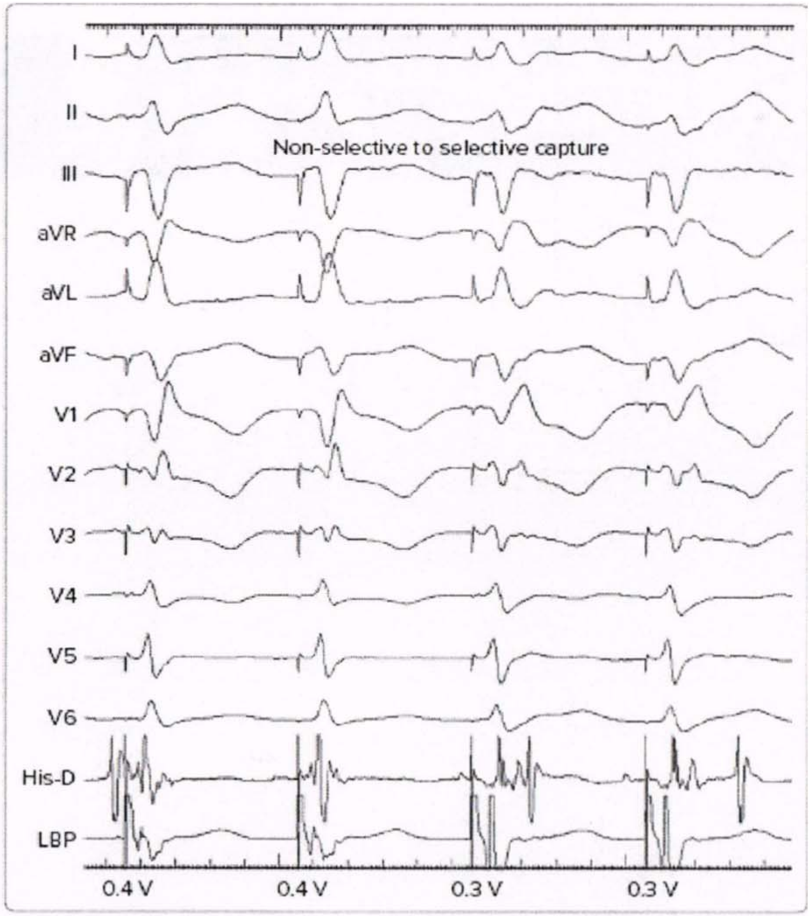
Current of injury



Heart Rhythm 2022;19:1281

Positioning lead

- LBBP can be selective or nonselective
  - Nonselective:
    - no isoelectric segment before onset of paced QRS complex
    - Indicating direct activation of myocardium in addition to LBB
  - Selective:
    - distinct isoelectric segment before onset of paced QRS com plex
  - At “working output” ns-LBBP is almost always present
    - Transition from ns- to s- is usually observed shortly after lead fixation and often times rarely observed during follow-up



Non-selective to Selective Left Bundle Branch Capture

Card Fail Rev. 2021; Mar 7:e13

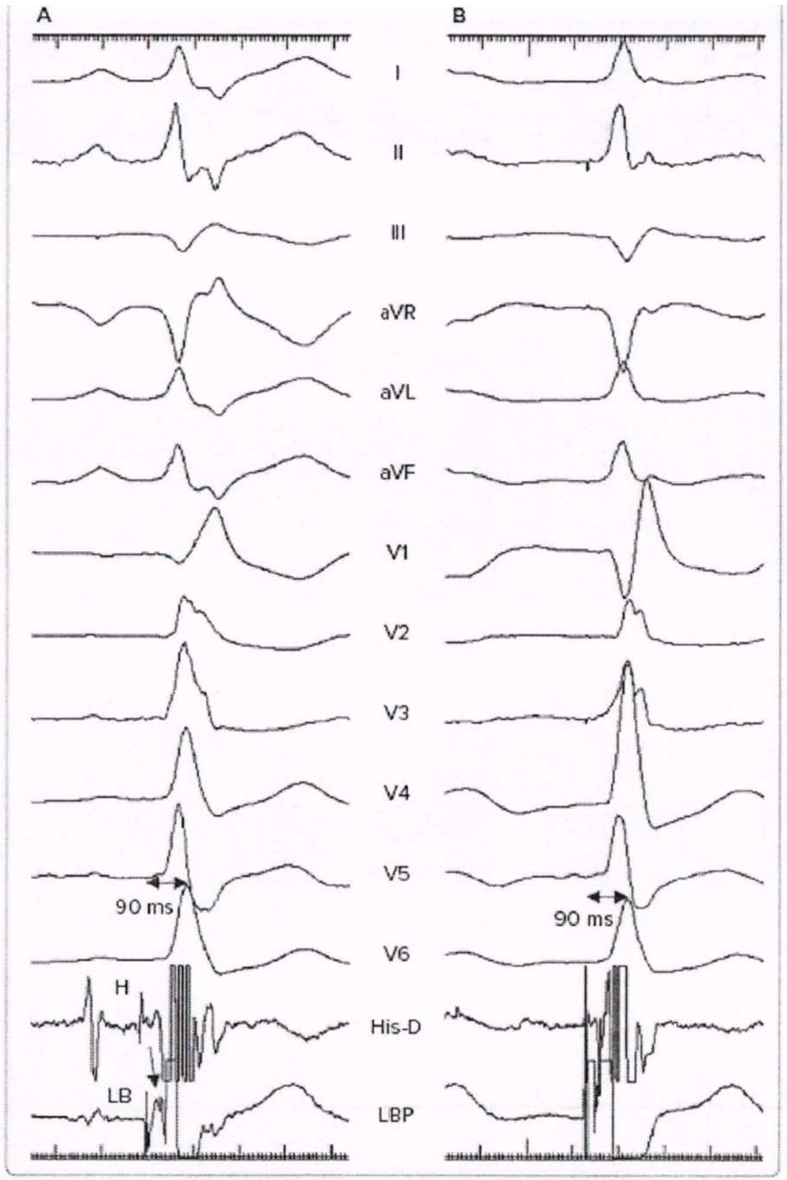
Confirming left bundle area capture

- V6RWPT- surrogate of activation delay of lateral LV
  - Narrow QRS, this is < 50 ms and with LBBB it is > 60ms
  - With pacing
    - measure from pacing stimulus to peak of R wave in V6
    - Realize that this measurement was made in patients with dominant R wave in V5/6 and it is unclear in presence of rS

- Sudden increase in V6RWPT $\geq$15 msec at reduced pacing out puts: probably means loss of LBB capture

Confirming capture

Delay of LBB potential to V6RW PT in intrinsic rhythm should be equal to stimulus to V6RWPT



Physiology-based ECG Criteria for Left Bundle Branch Capture

Card Fail Rev 2021 Mar: 7: e13

Confirming capture

- Acceptable thresholds for LBBAP capture are < 1-1.5 V @0.5 ms and bipolar sensing > 4 mV

- Stylet driven leads:
  - Larger lead diameters
  - Be careful not to have outer lead body turn over inner coil and helix which can cause helix retraction

Left Bundle pacing

- Patients with cardiomyopathy and conduction system abnormalities?
- Retrospective observational analysis
  - 325 pts with CM, EF $\leq$ 50%, NYHA II-IV
  - 44% had ischemic CM and 39% had LBBB
  - LBBAP was successful in 85% (277/325)
  - QRSd ↓ and EF ↑
  - Lead dislodgement in 5/325 and acute LV perf in 10/325
  - Initial recommendation place lead 1.5 cm apical to His but septal leaflet of TV could be perforated

J Am Coll Cardiol EP 2021; 7(2): 135

BiV vs Conduction System Pacing + AVNA in HF patients with AF

- Retrospective study of BiV pacing, HBP/LBBP in HF pts with sx AF, narrow QRS, s/p AVNA
- 50 pts, 48% M,EF 39%, (5/15-1/22)
  - EF < 50%; QRSd ≤ 120ms
  - 13 (26%) BiV pacing
  - 27 (54%) HBP (backup pacing)
  - 10 (20%) LBBP
  - NYHA improved with HBP and LBBP but not BiV pacing
  - LVEF improved in HBP (39->49%); LBBP (28->40%); but not with BiV pacing (38->37%)
  - LBBP had more stable pacing parameters

J Cardiovasc. Dev Dis 2022,9,209

Sx improvement with CSP
(72% HBP; 80% LBBP)

CSP
-Less HF hospitalizations
-Reduced use of diuretics

Echocardiographic outcomes of patients by pacing modality at baseline and follow-u

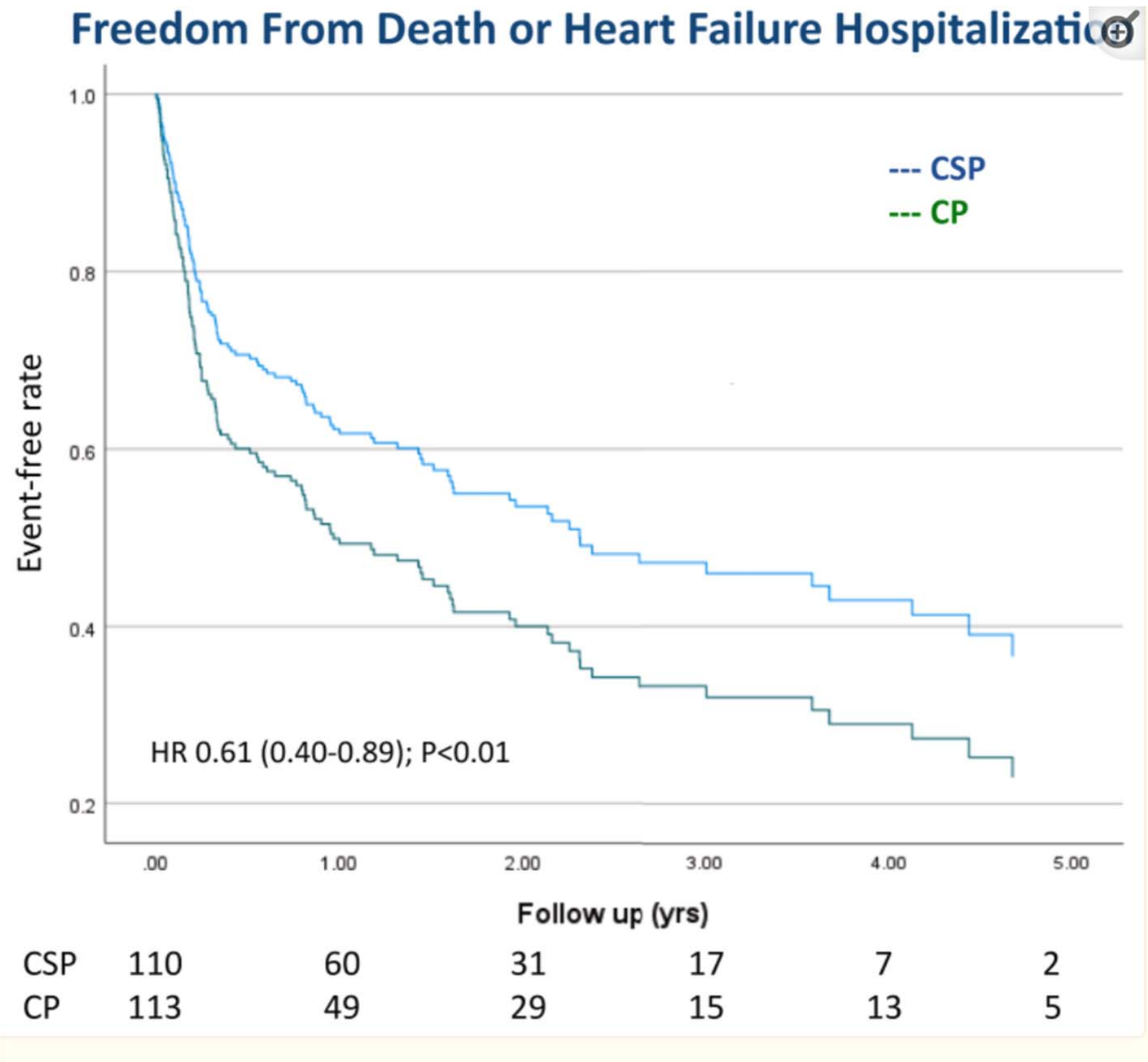
	BiV (*n* = 13)	**HBP (*n* = 25) ***	**LBBP (*n* = 10)**
Initial LVEF [%]	38 (35–40)	39 (31–46)	28 (20–43)
Follow-up LVEF [%]	37 (35–41)	49 (42–58)	40 (31–44)
p value: initial vs. follow-up	0.916	<0.001	0.041
Initial LVEDVi [mL/m^2]	82 (±17)	72 (±21)	89 (±22)
Follow-up LVEDVi [mL/m^2]	84 (±19)	61 (±18)	81 (±21)
p value: initial vs. follow-up	0.509	0.006	0.002
Initial LVESVi [mL/m^2]	51 (±12)	45 (±18)	63 (±21)
Follow-up LVESVi [mL/m^2]	53 (±14)	32 (±13)	50 (±18)
p value: initial vs. follow-up	0.551	<0.001	0.004

J cardiovasc. Dev Dis 2022,9,209

Conduction system pacing (CSP) vs conventional pacing (CP) after AVNA

- Retrospective observation study of AVNA pts (1/2015- 10/2018)
  - 233 pts
    - CSP- 84 HBP and 46 LBBP (110 pts)
    - CP – RV or BiV (113 pts)
      - f/u 27 ± 19 m
    - 52% male; EF 43 ±15%; LVEF lower and LBBB more often in CP group
  - QRS interval increased in both groups
  - EF improved in both groups (was higher in CSP group to begin with)
    - 46.5 ± 14.2->51.9 + 11.2 %(CSP) and 36.4 + 16.1-> 39.5 + 16 %(CP)
  - Primary endpoint
    - Combined first HF hospitalization or death
  - Secondary outcomes
    - Death from any cause; HF hospitalization if EF < 50% or if ≥ 50%
  - Safety endpoints
    - Rise in threshold of > 1 v or lead revision

Heart Rhythm O2. 2022 Aug; 3(4): 368–376.



48% CSP vs 62 % CP
($p < 0.01$)

No difference between HBP + LBBP

Heart Rhythm O2. 2022 Aug; 3(4): 368–376.

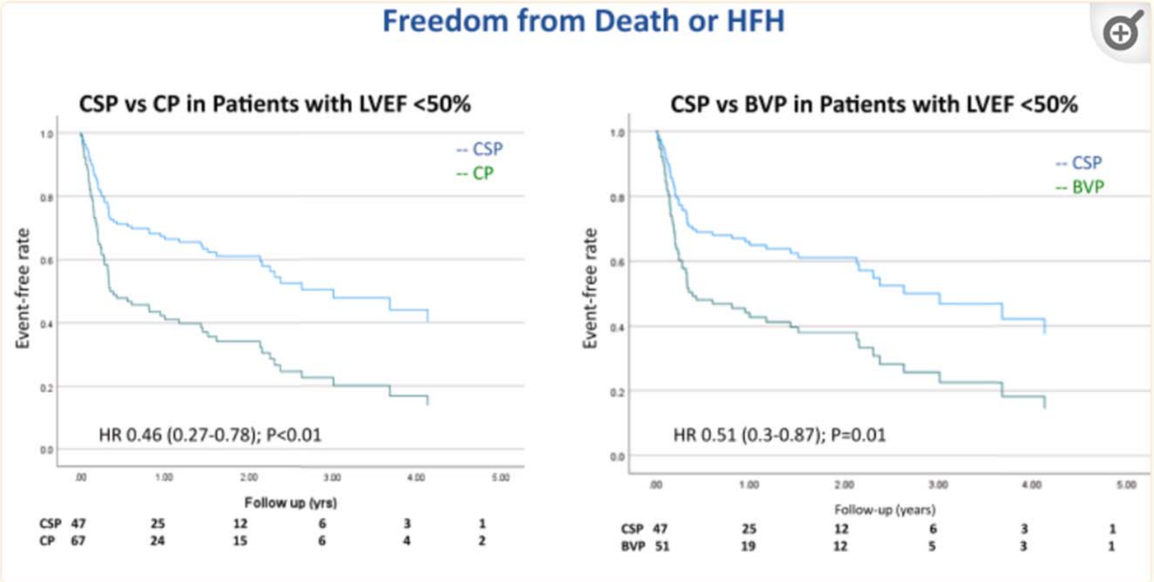


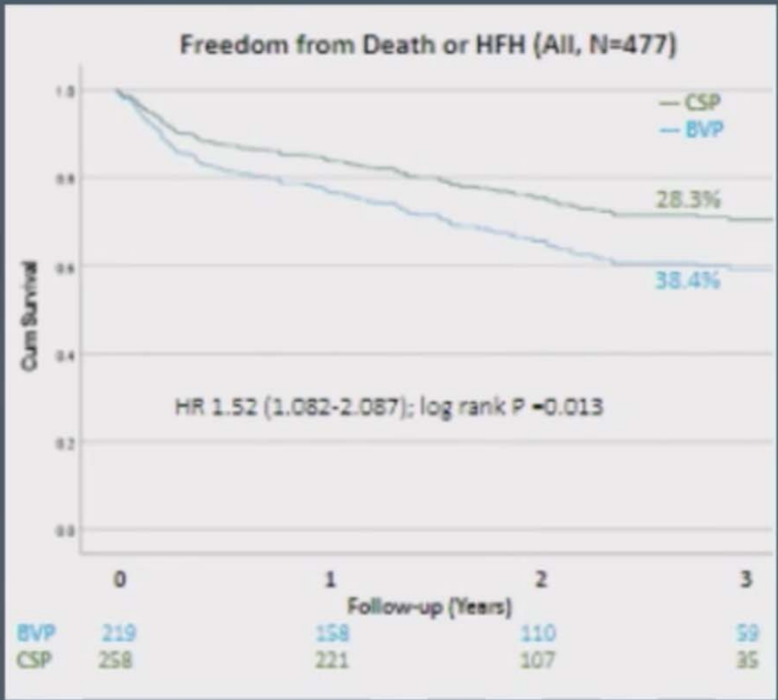
Figure 4

Subgroup analysis of primary composite outcome of time to death or heart failure hospitalizations among patients with left ventricular ejection fraction (LVEF) <50%. Conduction system pacing (CSP) vs conventional pacing (CP) and CSP vs biventricular pacing (BVP). Cox regression survival curves and multivariate analysis demonstrate significant reduction in the primary composite outcome (all-cause mortality or heart failure hospitalization) among patients with LVEF <50% when CSP was compared with CP or BVP.

Heart Rhythm O2. 2022 Aug; 3(4): 368–376

CSP in the Low LVEF Population

Non-randomized cohort of 477 patients undergoing traditional CRT or CSP



- 54% NICM
- 6.7% Mixed cardiomyopathy
- 52% LBBB
- 9% IVCD
- 9% RBBB
- 16% RV paced upgrade

Vijarayaman P et al Heart Rhythm 2022;19:1263-1271.

Conduction system pacing vs CRT?

- Prospective nonrandomized multicenter study 6/17-8/18 mean f/u 15m
  - NICM, LBBB,EF $\leq$ 50%, indications for CRT
    - Successful in 61/63 (97%)
  - QRSd-169$\pm$16 -> 118 $\pm$12 ms, LVEF 33$\pm$8 -> 55 $\pm$ 10%
- Many retrospective trials and meta- analysis studies
  - LBBAP vs CRT (8 nonrandomized studies)
  - Meta-analysis of 4 nonrandomized controlled studies
  - International LBBAP Collaborative Study
    - LBCT @ HRS 2022
    - LBCT @HRS 2023

JACC Clin Electrophysiol 2020 jul; 6(7):849
Heart + Vessels 2020 ;28 Jan
CJC Open 2021; 3(10):1282
LBCT; Heart Rhythm 2022
JACC May 21,2023

Use in CRT cases?

- LBBP-Resynch Study
  - Randomized Controlled Pilot Study of LBBP vs BiV pacing
  - NICM, cLBBB, LVEF ≤ 35%
  - 40 pts (22 LBBP vs 18 BiV)
  - LBBP group had ↑LVEF, ↓LVESV, ↓NT proBNP
- HOT-CRT trial
  - LBCT HRS 2023
  - Randomized, controlled, single blinded pilot study from 4/21-11/22
  - CM, EF≤ 35%, NYHA I-IIa
  - 100 pts (50 BiV vs 50 CSP)
    - 82% BiV success vs 96% CSP (HBP/LBBAP/LOT-CRT)
    - 8% Increase in EF vs 12% increase in EF
    - No difference in safety or HFH/death

J Am Coll Cardiol. 2022 Sep, 80 (13) 1205–1216
Heart Rhythm May 2023

CSP vs. CRT in Low LVEF Population

Favors CSP

- Non-randomized data suggest more profound improvement in LV function in traditional LBBB population
  - More super responders
  - ?higher "response rate"
- May be technically easier

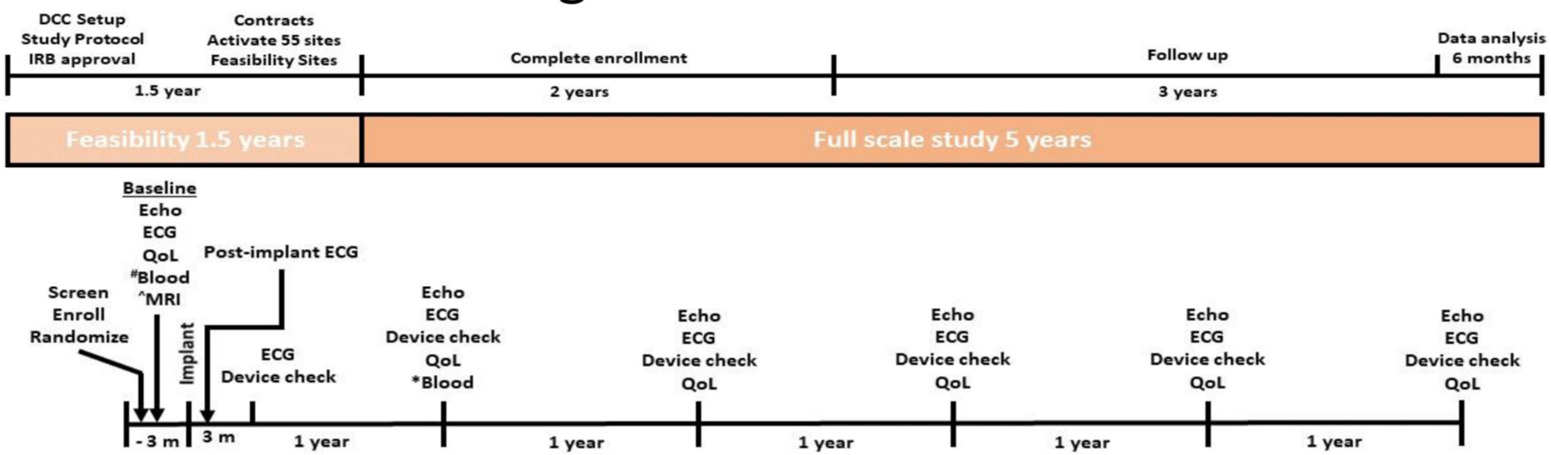
Favors traditional CRT

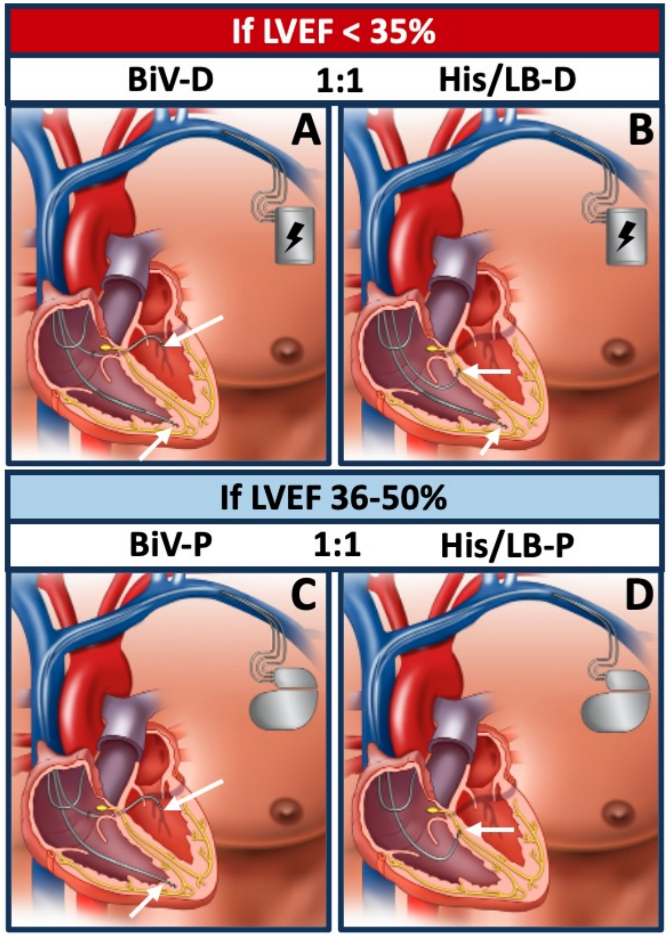
- Has been subjected to numerous randomized studies over a 20 year time period
- No well powered randomized trials of CSP vs. traditional CRT
- Data for CSP in atypical LBBB, IVCD, RV pacing upgrades, and RBBB is sparse
- Majority of patients in CSP studies are non-ischemic (approx. 70%)
- Extraction of traditional CS leads is very well studied
- Implantation success with CSP with highly experienced operators was feasible in only 82% of patients

PCORI Trial: Left vs. Left CRT

Co-PI: Mihail Chelu, MD and Kenneth A. Ellenbogen, MD

- Prospective, randomized, trial of 2,136 patients from 55 enrolling sites in the US and Canada; any indication for pacing for bradycardia or CRT
- Practical Trial costing over 31 million





- **<u>Primary Outcomes</u>:**

  Efficacy: Death for any cause, Hospitalization for HF

  Safety: Percentage of device related complications

- **<u>Secondary Outcomes</u>:**

  Disease Specific QOL: KCCQ-12

  Disease Specific Distress: Cardiac Anxiety Questionnaire

  Device Measured Patient Activity

  Composite: death of any cause, HF hospitalization, LVESVi

  Death of any cause

  Cardiovascular Death

  Hospitalization for Heart Failure

  Hospitalization for Cardiovascular Cause

  Hospitalization for any cause

  Battery Longevity

  Serum Biomarkers (NT-proBNP)

- **<u>Tertiary</u>:**

  NYHA Class

  Echocardiographic measures: LVEF, LVESVi

  Appropriate ICD therapy for ventricular tachyarrhythmias

  Incidence of atrial arrhythmias/ BNP level

Planned or ongoing studies

Larger RCTs (defined N≥100) + smaller RCTs

In planning / proposed

Recently completed

	Brady	Heart Failure				
	AVB/Pacing Indication	BLOCK HF AVB+ EF<50%	HFpEF EF≥50%	HFmEF EF 40-49%	HFrEF (EF < 40 %) Non CRT-indicated	HFrEF (EF < 40 %) CRT-indicated
HBP	4 small RCTs; 1 small RCT	2 small RCTs	1 small RCT		**HOPE-HF**. His AV opt vs non-His N=198 NCT02671903; 3 small RCTs	
CSP	**PhysioVP-AF**. CSP vs RVP N=400 NCT05367037; **PHYSPAVB**. CSP vs RVP N=200 NCT05214365; 3 small RCTs	**myPACE**. Lower HR setting vs 60bpm N=130 NCT04721314; **PACE-FIB**. CSP+AVNA vs GDMT N=334 NCT05029570; 1 small RCT			**CONSYST-CRT**. CSP vs CRT N=130 NCT05187611	**HIS-alt_2**. CSP vs CRT N=125 NCT04409119; 2 small RCTs
LBBP/ LBBAP	**LEAP-Block**. LBBP vs RVP N=458 NCT04730921; 2 small RCTs; **LEAP-pilot, LEAP**. LBBAP vs RVP N=470 NCT04595487, NL9672	**RAFT-P&A**. CSP+AVNA vs CRT+AVNA N=285 NCT05428787; **OptimPacing**. LBBP vs RVP N=683 NCT04624763; **LEFT-HF**. LBBP vs RVP N=100 NCT05015660				**LEFT-BUNDLE-CRT Trial**. LBBAP vs CRT N=176 NCT05434962; **LeCaRT**. LBBAP vs CRT, N=170 NCT05365568; 1 small RCT
CSP+CRT HOTCRT LOTCRT		**HOT-CRT**. HOT/LOT CRT vs CRT N=100 NCT04561778	**RAFT-Preserved**. CSP±CRT vs CRT vs GDMT N=370) NCT04582578		1 small RCT HOT v VVI; 1 small RCT HOT v CRT	**HOT-CRT**. HOT/LOT CRT vs CRT N=100 NCT04561778; **HIS-CRT**. HOTCRT vs CRT N=120 NCT05265520

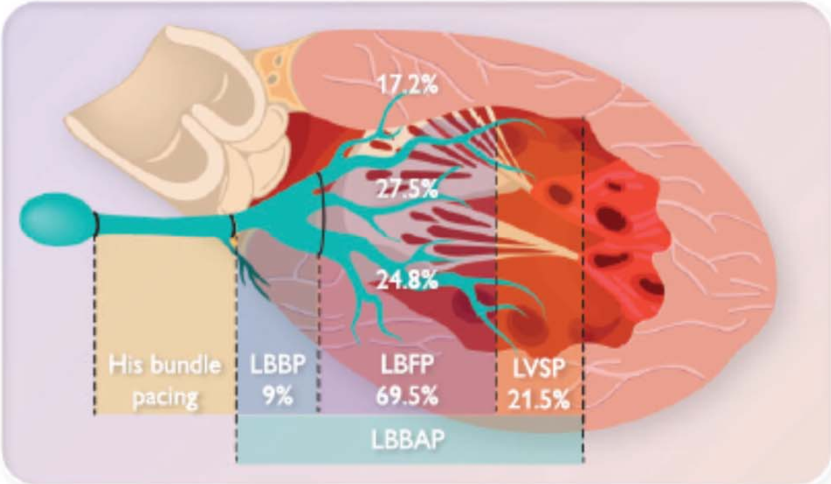
Active studies posted on clinicaltrials.gov or other public trial website as of 30-AUG-2022

MELOS — MULTICENTER EUROPEAN LEFT BUNDLE BRANCH AREA PACING OUTCOMES STUDY

Prospective, multicenter, registry-based observational study

2533 Participants

14 European centres



Independent predictors of LBBAP lead implantation failure

Heart failure indication	OR 1.49, 95% CI 1.01–2.21
Baseline QRS duration, per 10 ms	OR 1.08, 95% CI 1.03–1.14
LVEDD, per 10 mm increase	OR 1.53, 95% CI 1.26–1.86

LBBAP implantation success

Bradycardia indication success	92.4%
Heart failure indication success	82.2%

LBBAP lead complications	**8.3%**
• Acute perforation to LV	3.7%
• Lead dislodgement	1.5%
• Acute chest pain	1.0%
• Capture threshold rise	0.7%
• Acute coronary syndrome	0.4%
• Trapped/damaged helix	0.4%
• Delayed perforation to LV	0.1%
• Other	0.7%

Eur Heart J
. 2022 Oct 21;43(40):4161-4173

Complications

- Perforation of IVS (0-14.! %)
  - Watch COI
  - Unipolar COI < 2.3 mV indicates perforation
  - Good positions- show COI of 9mV
  - Also COI <35% of V egm and ring >tip COI amplitude-> perforation

- Acute fall in pacing impedance to < 450 ohms or fall > 200 ohms
  - Acute perforation is usually asx
  - Late occurrence of perforation -> 0.1-0.3%
    - ? oral anticoagulation
- Rare: acute coronary events, fistula with septal perforators, worsening of TR
- MELOS-> loss of terminal R wave in V1 over followup was 4%
- LOOK AT 12 LEAD DURING FOLLOWUP

- **? long term effects of fatigue on lead body**
- **? extraction of lumenless leads**

2023 HRS/APHRS/LAHRS guideline on cardiac physiologic pacing for the avoidance and mitigation of heart failure

Mina K. Chung, MD, FHRS (Chair)[1,*] Kristen K. Patton, MD, FHRS (HRS Vice-Chair)[2,*]
Chu-Pak Lau, MD, FHRS, CCDS (APHRS Vice-Chair)[3]
Alexander R. J. Dal Forno, MD (LAHRS Vice-Chair)[4]
Sana M. Al-Khatib, MD, MHS, FHRS, CCDS,[5,*] Vanita Arora, MBBS, MD, FHRS,[6,*]
Ulrika Maria Birgersdotter-Green, MD, FHRS,[7,*] Yong-Mei Cha, MD, FHRS, FACC,[8,*]
Eugene H. Chung, MD, MPH, FHRS,[9,*] Edmond M. Cronin, MB BCh BAO, FHRS,[10,*]
Anne B. Curtis, MD, FHRS,[11,*] Iwona Cygankiewicz, MD, PhD,[12,†]
Gopi Dandamudi, MBA, MD, FHRS,[13,*] Anne M. Dubin, MD, FHRS, CEPS-P,[14,‡]
Douglas P. Ensch, AEET,[1,§] Taya V. Glotzer, MD, FHRS, FACC,[15,*]
Michael R. Gold, MD, PhD, FHRS,[16,*] Zachary D. Goldberger, MD, MS, FHRS, CCDS,[17,*]
Rakesh Gopinathannair, MD, MA, FHRS,[18,*] Eiran Z. Gorodeski, MD, MPH,[19,¶]
Alejandra Gutierrez, MD,[20,*] Juan C. Guzman, MD, MSc,[21,*]
Weijian Huang, MD, FHRS,[22,#] Peter B. Imrey, PhD,[1,23,*]
Julia H. Indik, MD, PhD, FHRS,[24,*] Saima Karim, DO, FHRS,[25,**]
Peter P. Karpawich, MD, MS, FHRS,[26,‡] Yaariv Khaykin, MD, FHRS,[27,*]
Erich L. Kiehl, MD, MS,[28,*] Jordana Kron, MD, FHRS,[29,*]
Valentina Kutyifa, MD, PhD, FHRS,[30,*] Mark S. Link, MD, FHRS,[31,*]
Joseph E. Marine, MD, MBA, FHRS,[32,*] Wilfried Mullens, MD, PhD,[33,*]
Seung-Jung Park, MD, PhD,[34,#] Ratika Parkash, MD, MS, FHRS,[35,*]
Manuel F. Patete, MD,[36,††] Rajeev Kumar Pathak, MBBS, PhD, FHRS,[37,#]
Carlos A. Perona, MD,[38,††] John Rickard, MD, MPH,[1,*]
Mark H. Schoenfeld, MD, CCDS, FHRS, FACC, FAHA,[39,*] Swee-Chong Seow, MD, FHRS,[40,#]
Win-Kuang Shen, MD, FHRS,[41,*] Morio Shoda, MD, PhD,[42,#]
Jagmeet P. Singh, MD, PhD, FHRS,[43,*] David J. Slotwiner, MD, FHRS, FACC,[44,*]
Arun Raghav M. Sridhar, MBBS, MPH,[2,*] Uma N. Srivatsa, MBBS, MS, FHRS,[45,*]
Eric C. Stecker, MD, MPH, FHRS, FACC,[46,‡‡] Tanyanan Tanawuttiwat, MD, MPH, FHRS,[47,*]
W. H. Wilson Tang, MD, FHFSA,[1,¶] Carlos Andres Tapias, MD,[48,††]
Cynthia M. Tracy, MD,[49,*] Gaurav A. Upadhyay, MD, FHRS, FACC,[50,*]
Niraj Varma, MA, MD, PhD, FRCP,[1,*] Kevin Vernooy, MD, PhD, FESC, FEHRA,[51,*]
Pugazhendhi Vijayaraman, MD, FHRS,[52,*]
Sarah Ann Worsnick, PAC, FHRS, CEPS, CCDS,[52,*] Wojciech Zareba, MD, PhD,[30,†]
Emily P. Zeitler, MD, MHS, FHRS[53,*]

Document Reviewers: Nestor Lopez-Cabanillas, MD; Kenneth A. Ellenbogen, MD, FHRS; Wei Hua, MD, FHRS; Takanori Ikeda, MD, PhD; Judith A. Mackall, MD, FHRS; Pamela K. Mason, MD, FHRS; Christopher J. McLeod, MBChB, PhD, FHRS; Theofanie Mela, MD; Jeremy P. Moore, MD, MS, FHRS, CCDS, CEPS-P; Laurel Kay Racenet, MSN, FNP, FHRS, CEPS, CCDS

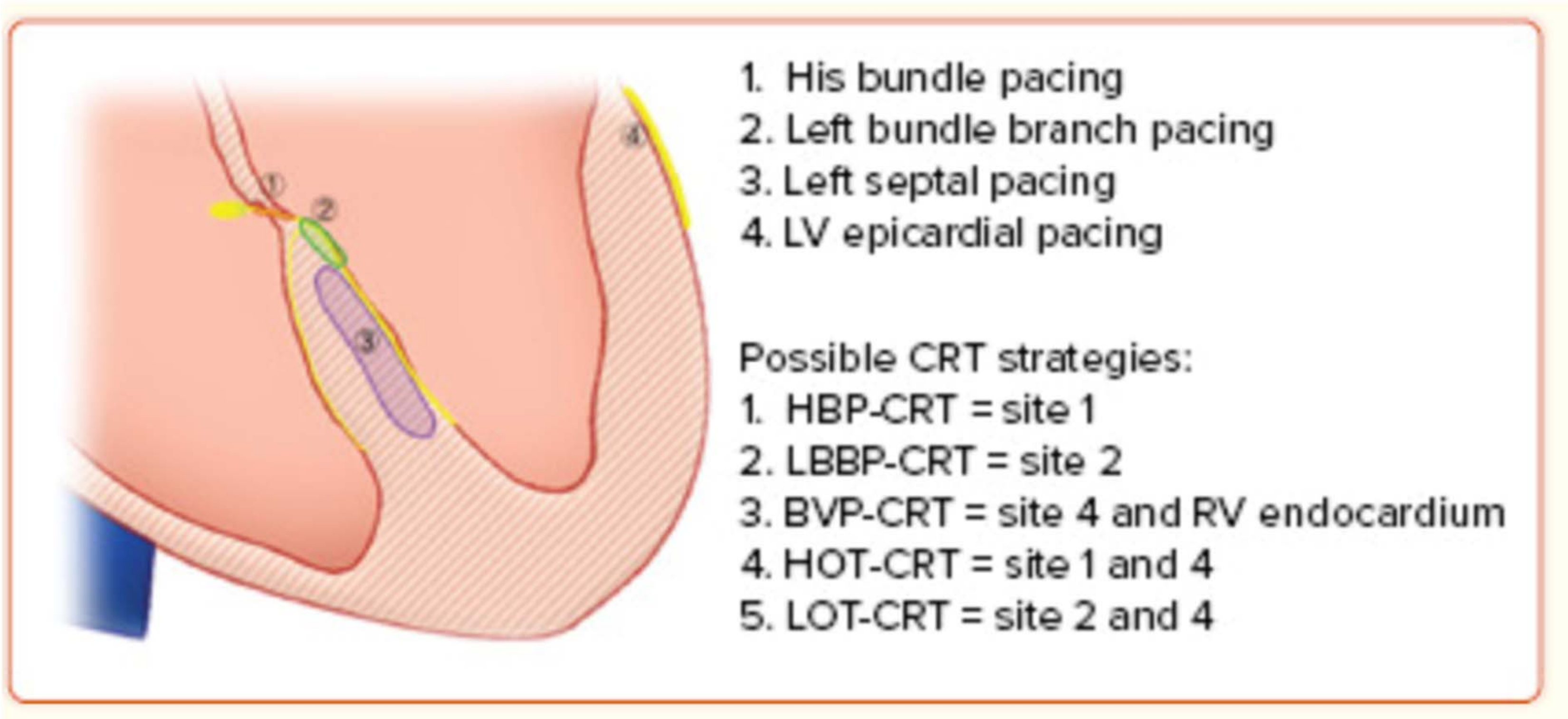
From the [1]*Cleveland Clinic, Cleveland, Ohio,* [2]*University of Washington, Seattle, Washington,* [3]*University of Hong Kong, Hong Kong, China,* [4]*Hospital SOS Cárdio, Florianópolis, Brazil,* [5]*Duke University Medical Center, Durham,*

https://doi.org/10.1016/j.hrthm.2023.03.1538

PGL 5.6.0 DTD ■ HRTHM9841_proof ■ 13 May 2023 ■ 1:53 pm ■ ce

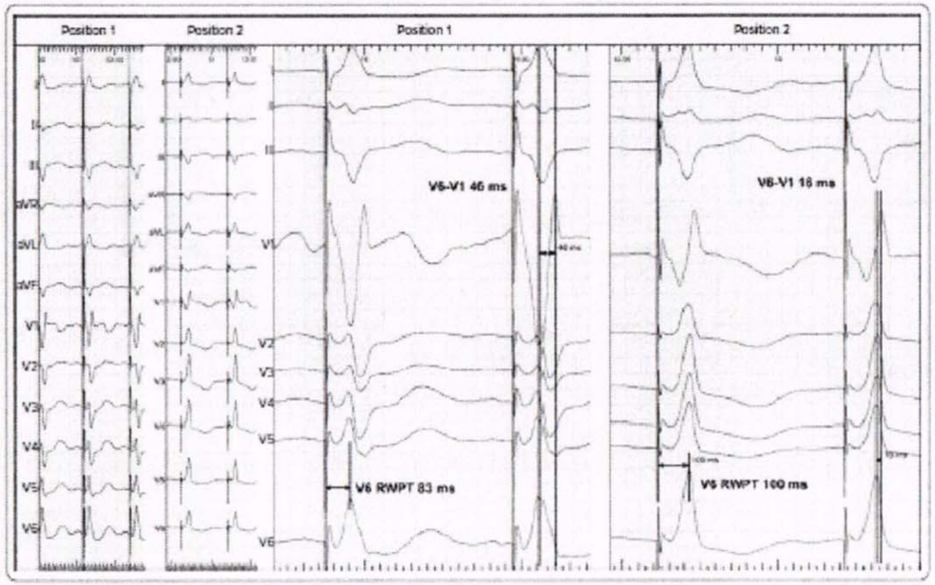
UNANSWERED QUESTIONS

- What is the most efficient implant technique?
- How do we define successful LB pacing?
- Only around since 2017
  - Ongoing prospective registries
  - One prospective pilot study
- If lead tip is in LV (such as LV perforation) is this a nidus for thrombus?
- How many times is too many to manipulate lead?
  - Ie screw it into the septum?
- Do we have to worry about the septal artery?



Arrhythm Electrophysiol Rev 2021 Apr; 10(1):51

Figure 7:



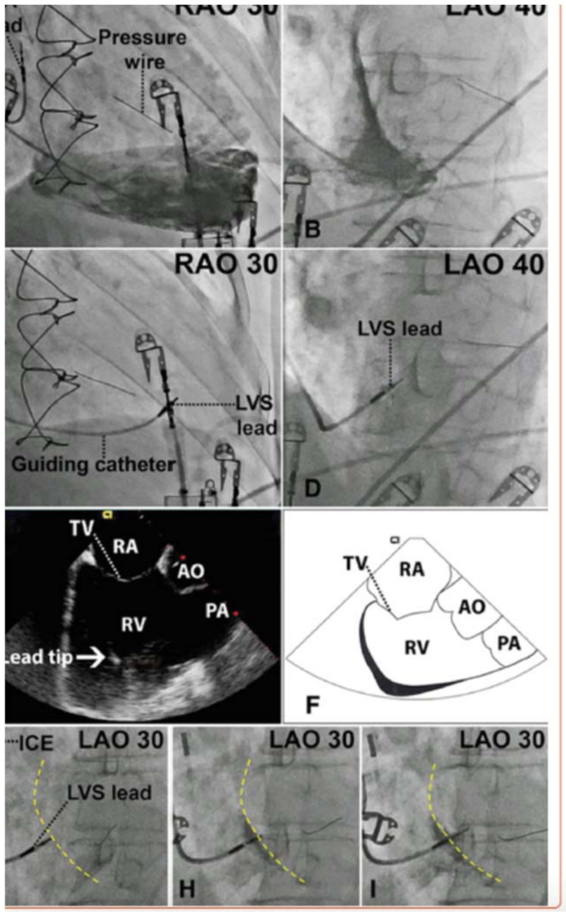
Using the V6–V1 Criterion for the Diagnosis of Left Bundle Branch Capture

Illustration of the practical application of the V6–V1 criterion for the diagnosis of left bundle branch (LBB) capture during the implantation procedure. In the first pacing position, lack of LBB potential and V6RWPT of 83 ms (i.e. over the used 75 ms cut-off) prompted the operator to look for a better position as he was not certain if LBB capture had been obtained. Unfortunately, all other subsequently obtained positions resulted in even longer V6RWPT of 100 ms and the procedure was concluded with only left ventricular septal (LVS) capture instead of LBB capture, which was most likely

Left bundle pacing

- Description of human anatomy in 1906 by Sunao Tawara
  - LB branches into 2 or 3 fascicles
    - which further divide into finer branches and ultimately the Purkinje fibers
  - Point stimulation at any branch will active this network
- LBBP and LV septal pacing
  - May be able to overcome distal conduction disease

Arrhythm Electrophysiol Rev 2021 Apr; 10 (1) : 51
Verleg Gustav Fischer 1906

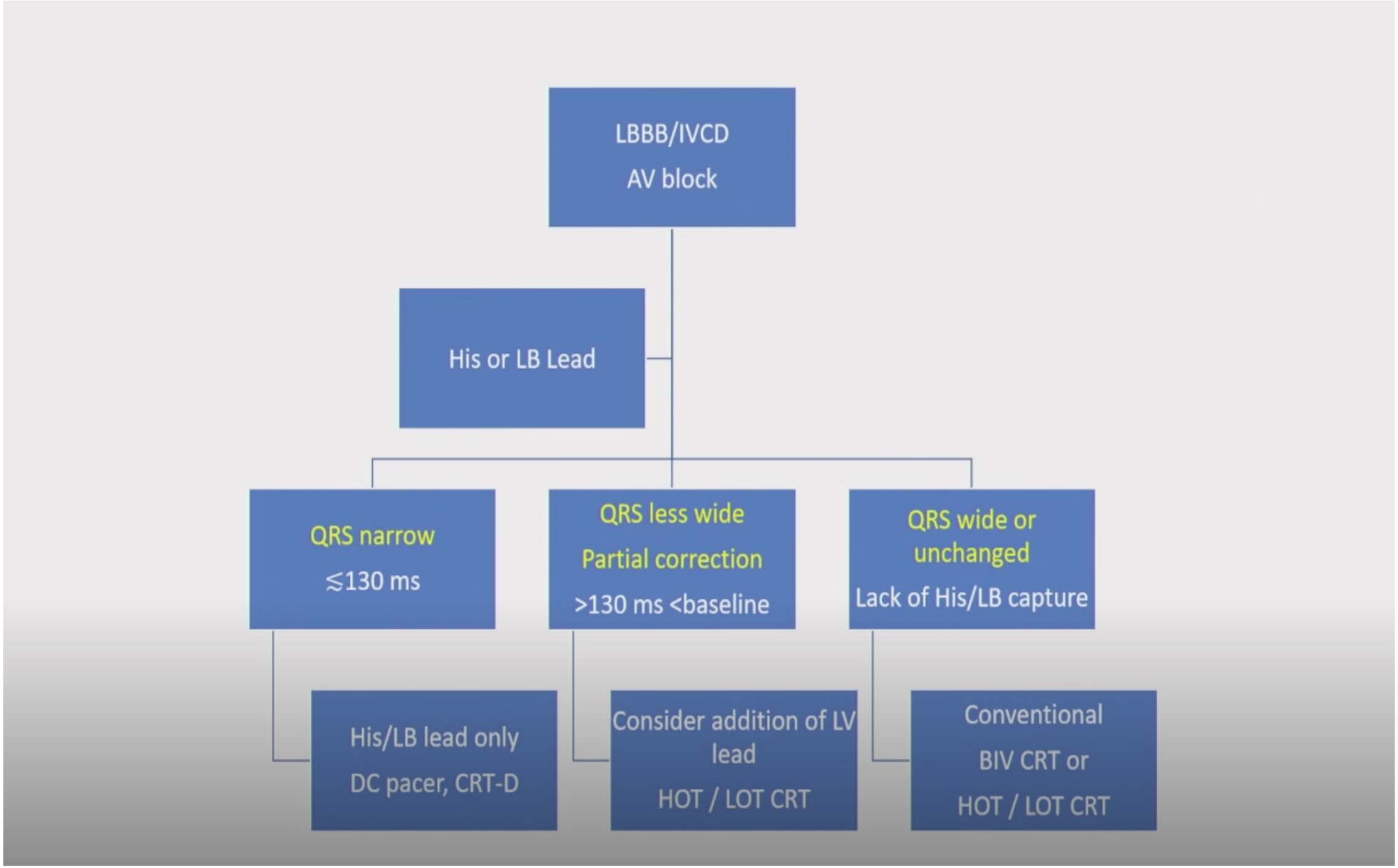


[Arrhythmia & Electrophysiology Review 2021;10(3):165–71.](#)

Criteria for left bundle branch pacing

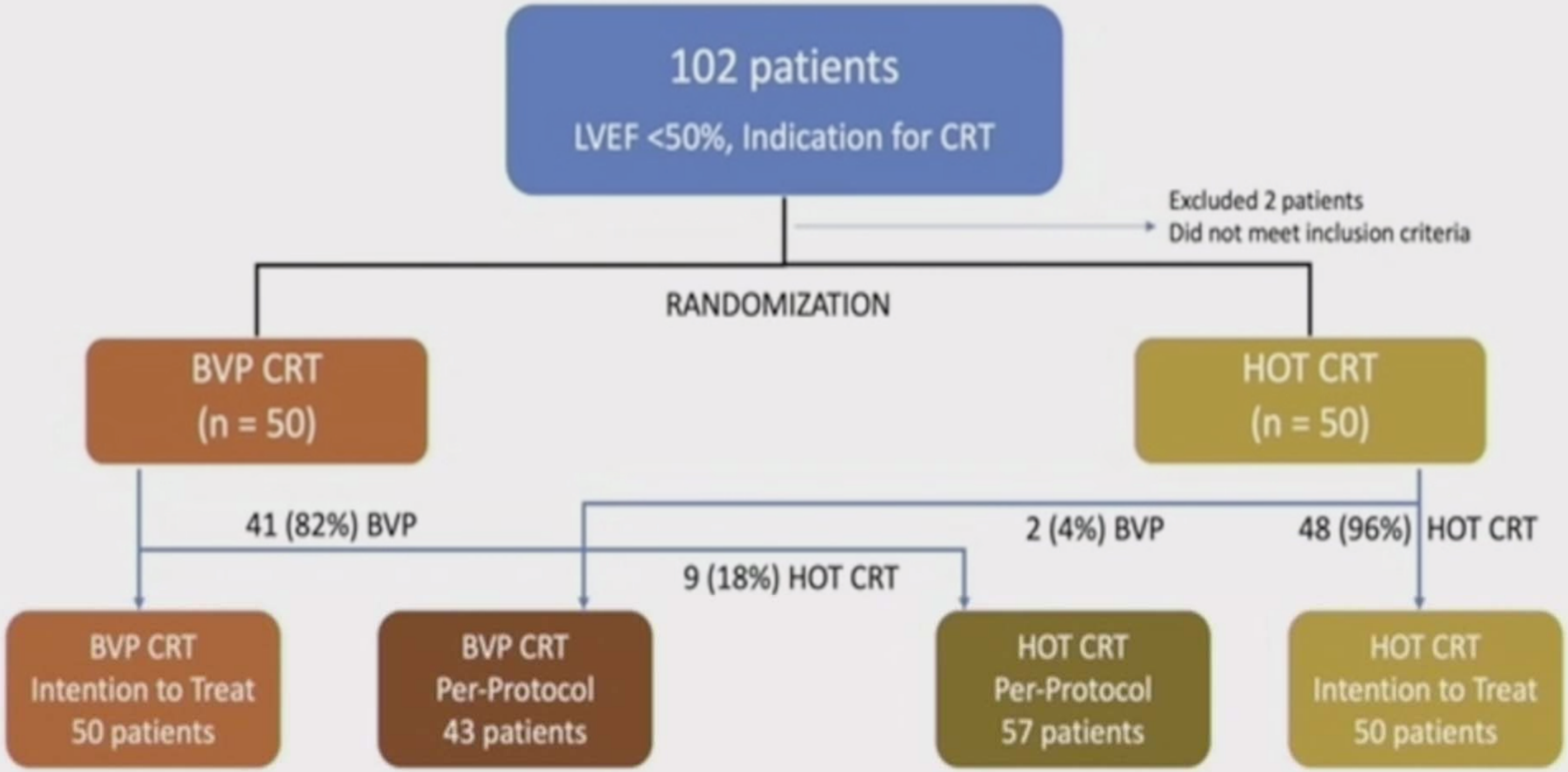
- RBBB pattern in V1
  - QR or rSR pattern
- Evaluation of peak of R wave in V6
  - R wave peak time (RWPT)
    - Abrupt shortening of interval between stimulus artifact and peak of R wave in V6 by at least 10 ms
    - Paced RWPT equivalent to unpaced V6 RWPT (if no conduction delay present) shows LB capture
    - ? 75 ms if have no conduction delay and 100 ms if have conduction delay

J Innov Cardac Rhythm Manage 2022; 13(1):4829

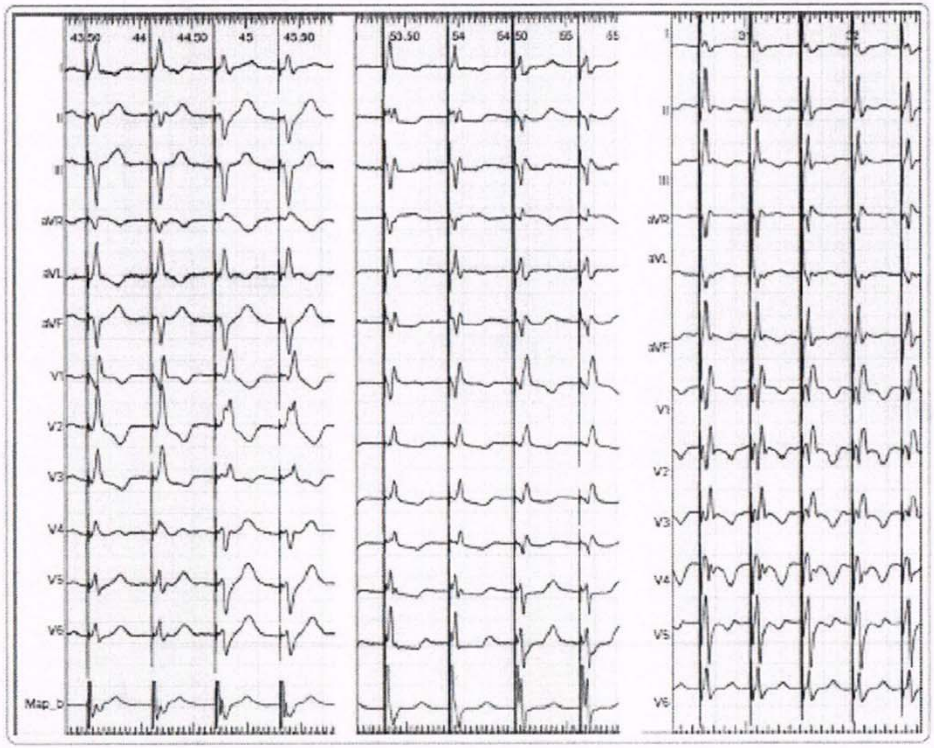

LBBB/IVCD
AV block
His or LB Lead
QRS narrow
≲130 ms
QRS less wide
Partial correction
>130 ms <baseline
QRS wide or unchanged
Lack of His/LB capture
His/LB lead only
DC pacer, CRT-D
Consider addition of LV lead
HOT / LOT CRT
Conventional
BIV CRT or
HOT / LOT CRT

KHRS 2023

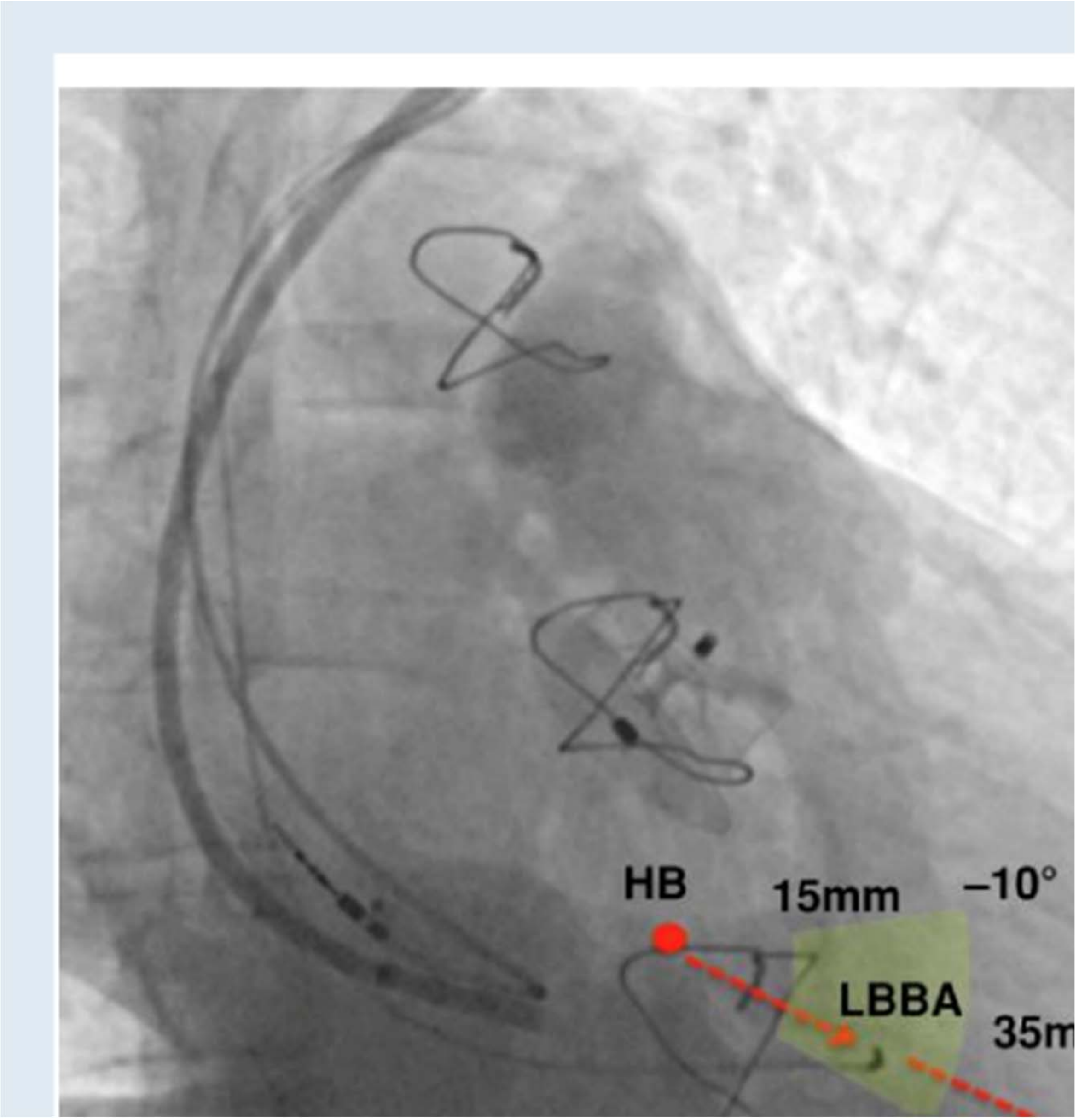
HOT CRT Trial Results



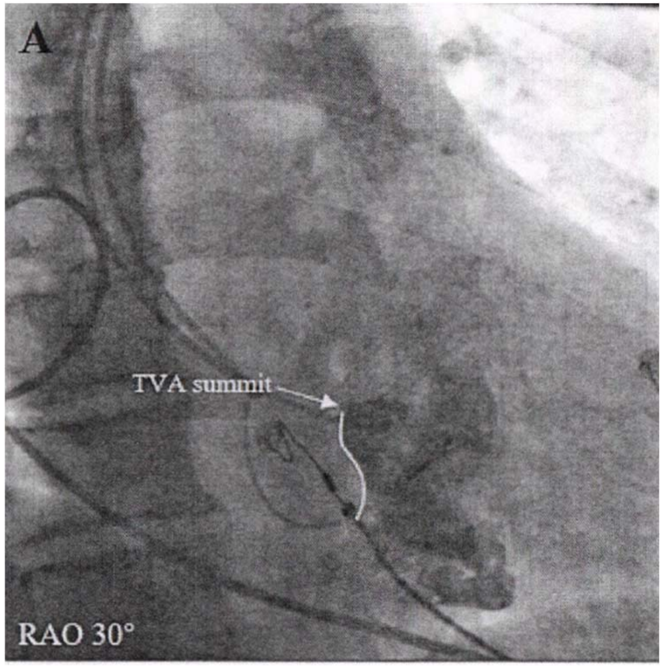
igure 5.

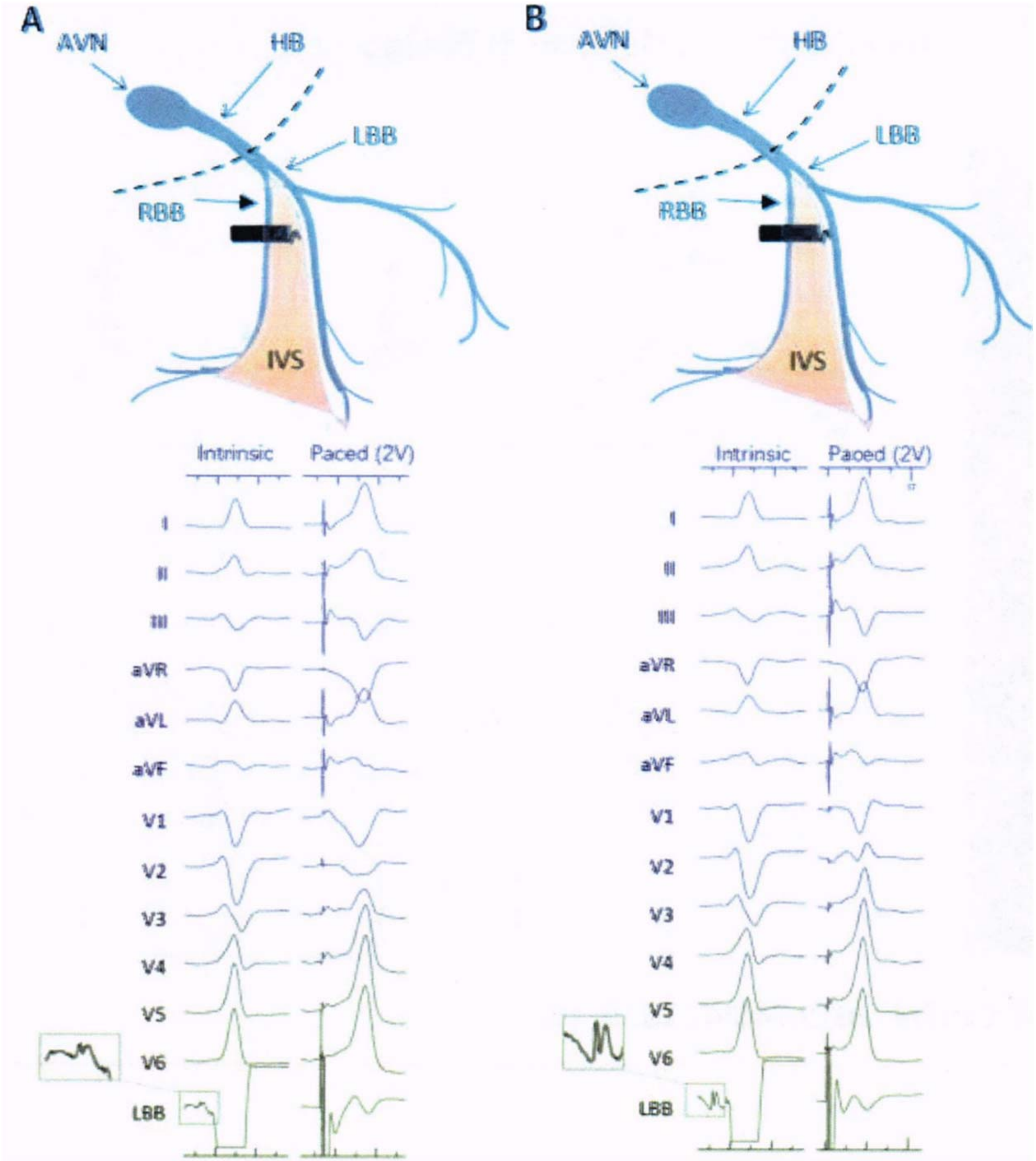


Transition from Non-selective to Selective Left Bundle Branch Capture

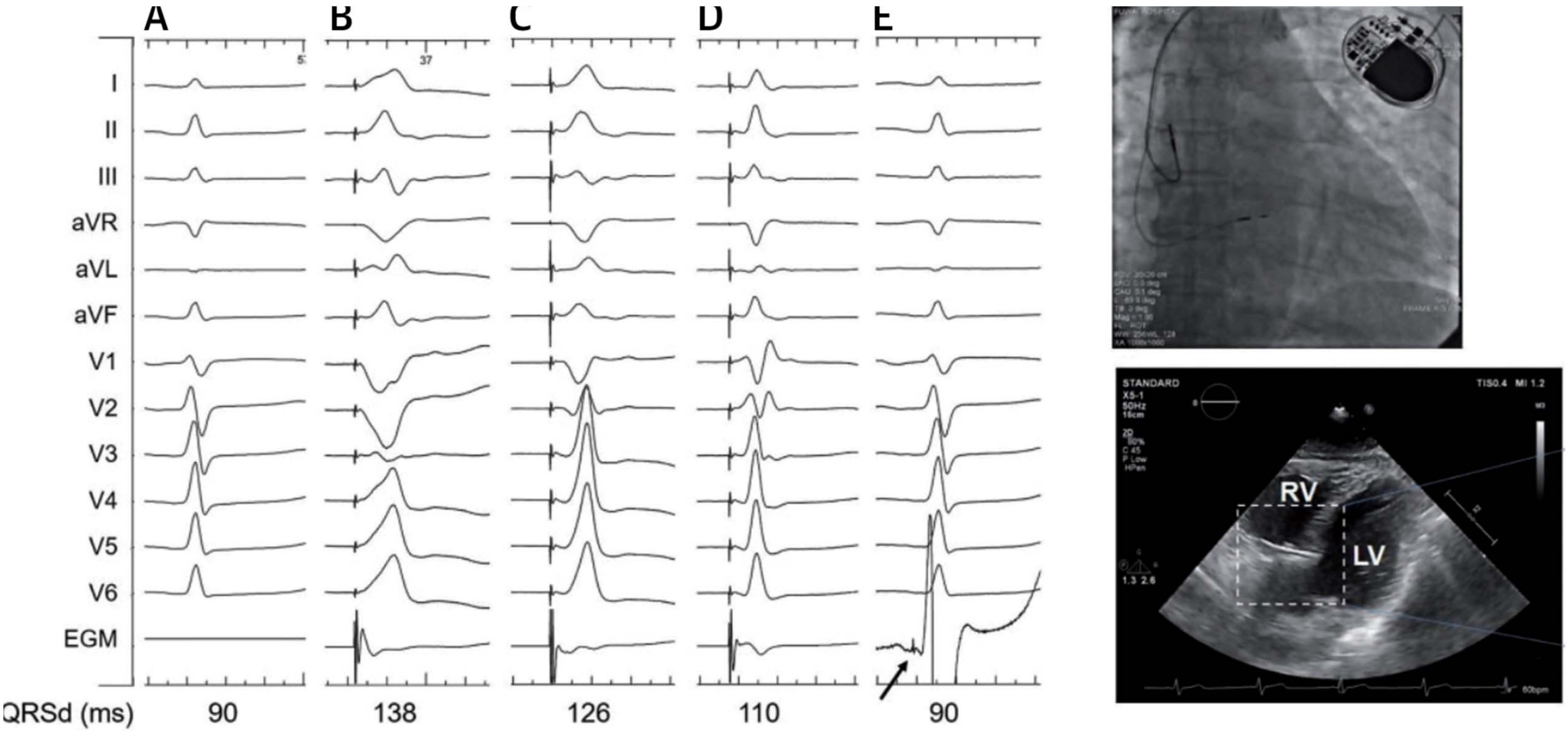


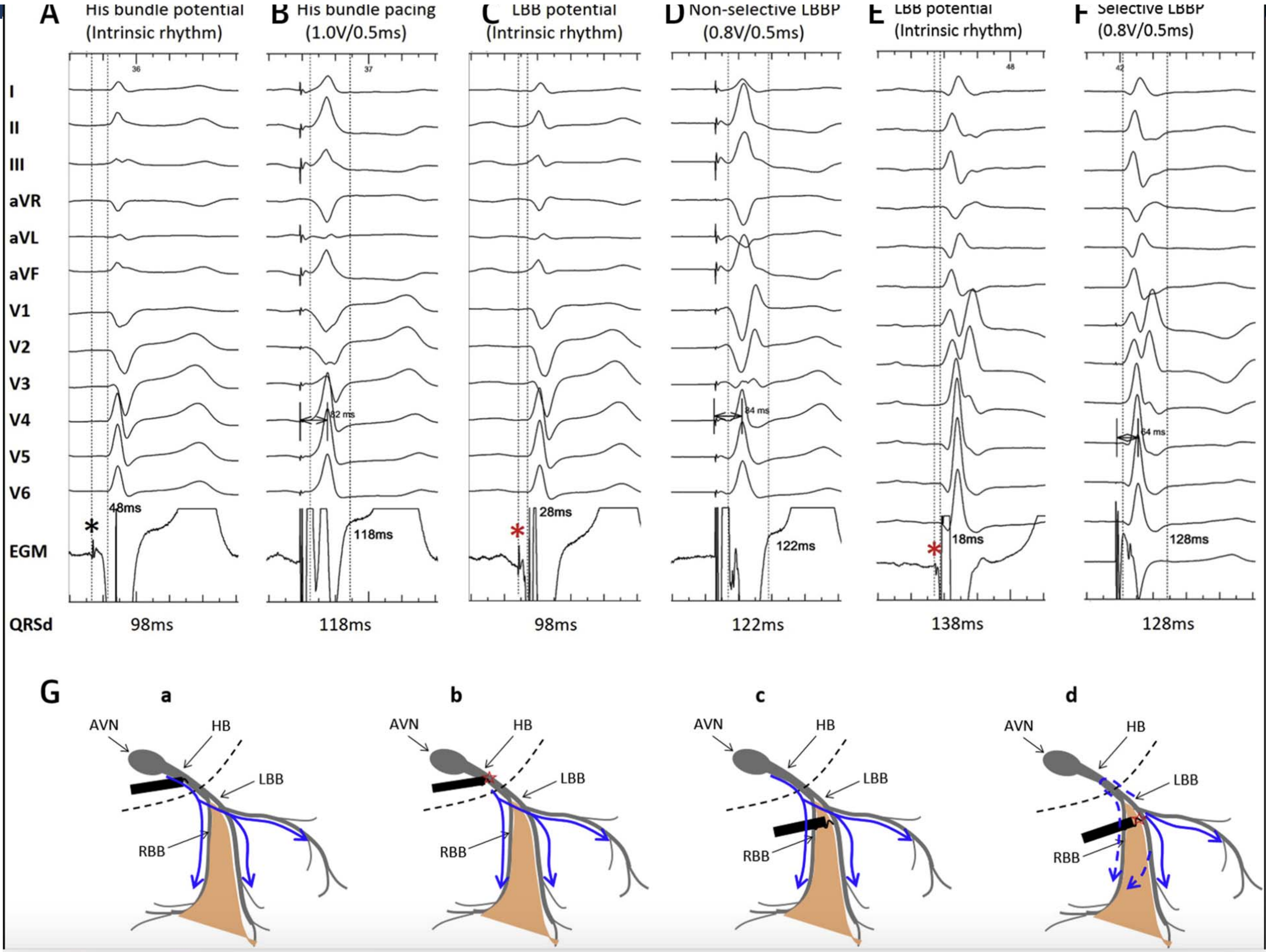
EP Europace volume 25, issue 4,April 2023
Page 1208; Burri H


A
TVA summit
RAO 30°



J Am Coll Cardiol 2019;74 (24):3039


A
B
C
D
E
37
I
II
III
aVR
aVL
aVF
V1
V2
V3
V4
V5
V6
EGM
QRSd (ms)
90
138
126
110
90
STANDARD
X5-1
50Hz
16cm
TIS0.4 MI 1.2
RV
LV
1.3 2.6
60bpm

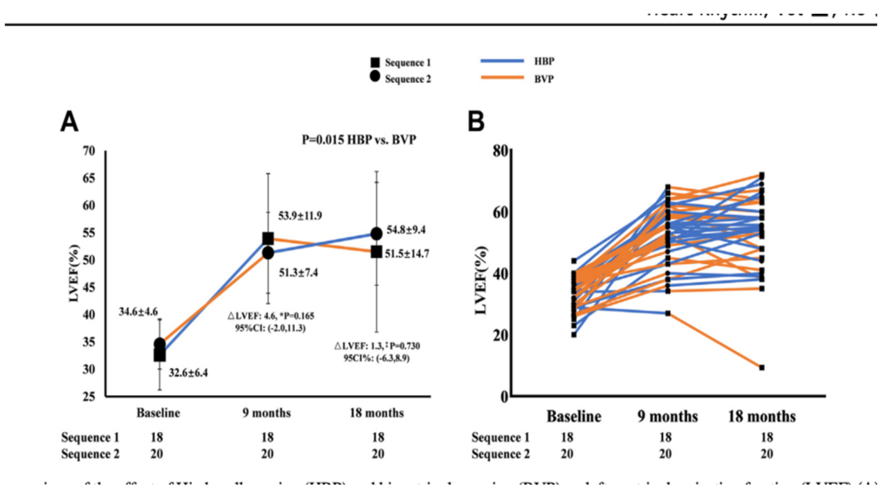


A His bundle potential (Intrinsic rhythm)
B His bundle pacing (1.0V/0.5ms)
C LBB potential (Intrinsic rhythm)
D Non-selective LBBP (0.8V/0.5ms)
E LBB potential (Intrinsic rhythm)
F Selective LBBP (0.8V/0.5ms)
I
II
III
aVR
aVL
aVF
V1
V2
V3
V4
V5
V6
EGM
QRSd
48ms
98ms
118ms
118ms
28ms
98ms
122ms
122ms
18ms
138ms
128ms
128ms
G
a
b
c
d
AVN
HB
LBB
RBB

KHRS 2023

HBP vs BiV pacing following AVNA in patients with AF and reduced EF: A multicenter, randomized, crossover study—The ALTERNATIVE-AF trial trial

- Multicenter, <u>prospective</u>, randomized, cross over study of PsAF + AVNA and EF≤ 40%
  - HBP vs CRT x 9 months and then switched in 50 pts
    - 72% male, 38 pts totally evaluated
  - Difference in EF
    - First 9 months: HBP 21.3% vs CRT 16.7 %
    - Second 9 months: 3.5% vs -2.4%
      - P = 0.015

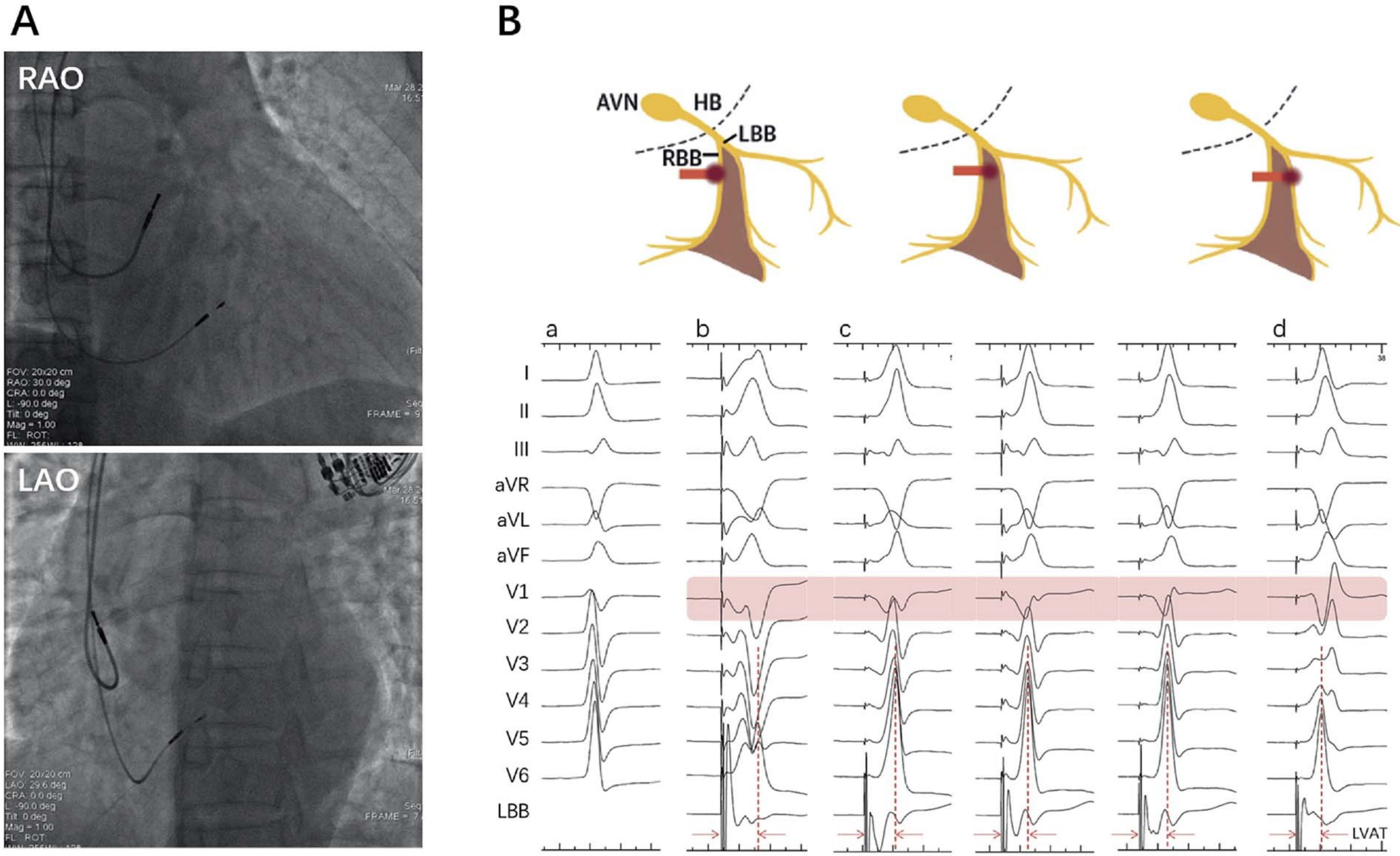


July 13, 2022DOI:https://doi.org/10.1016/j.hrthm.2022.07.009

Randomized CSP studies

- LBBB-Resynch (JACC 2022)
- HOT-CRT trial (HRS 2023)
  - Randomized, controlled, single blinded pilot of 100 pts
    - 82% (41/50) BiV vs 96% (48/50) HOT-CRT
      - 8% increase in EF vs 12% increase in EF

CENTRAL ILLUSTRATION: Left Bundle Branch Pacing



Zhang, S. et al. J Am Coll Cardiol. 2019;74(24):3039–49.

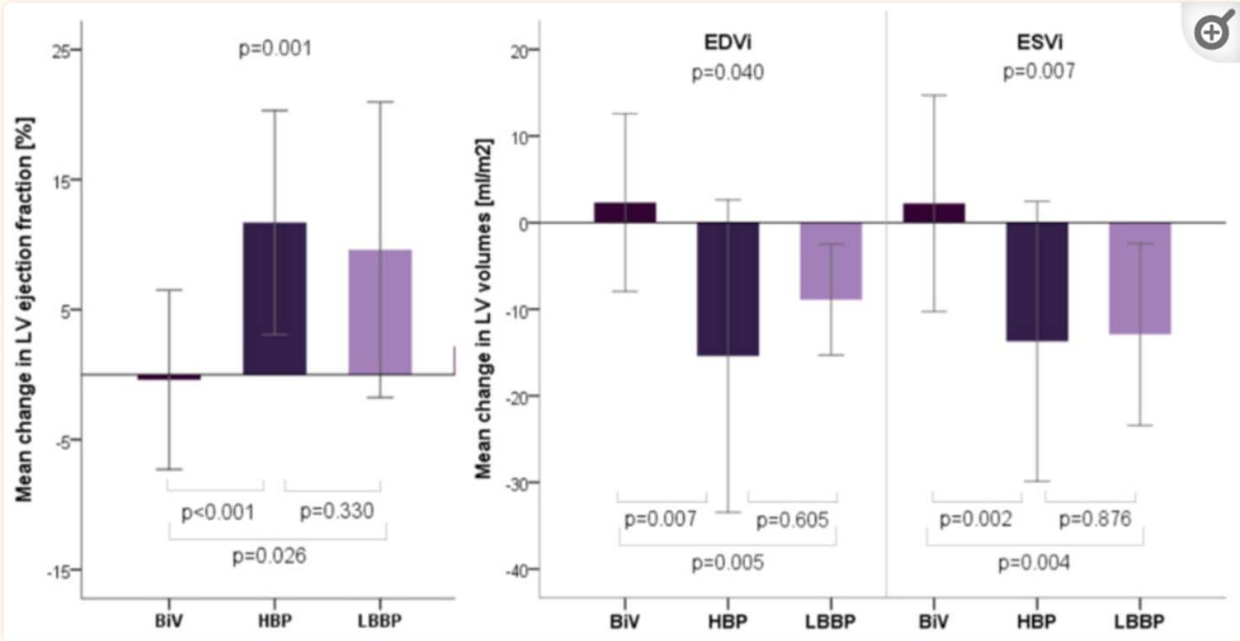
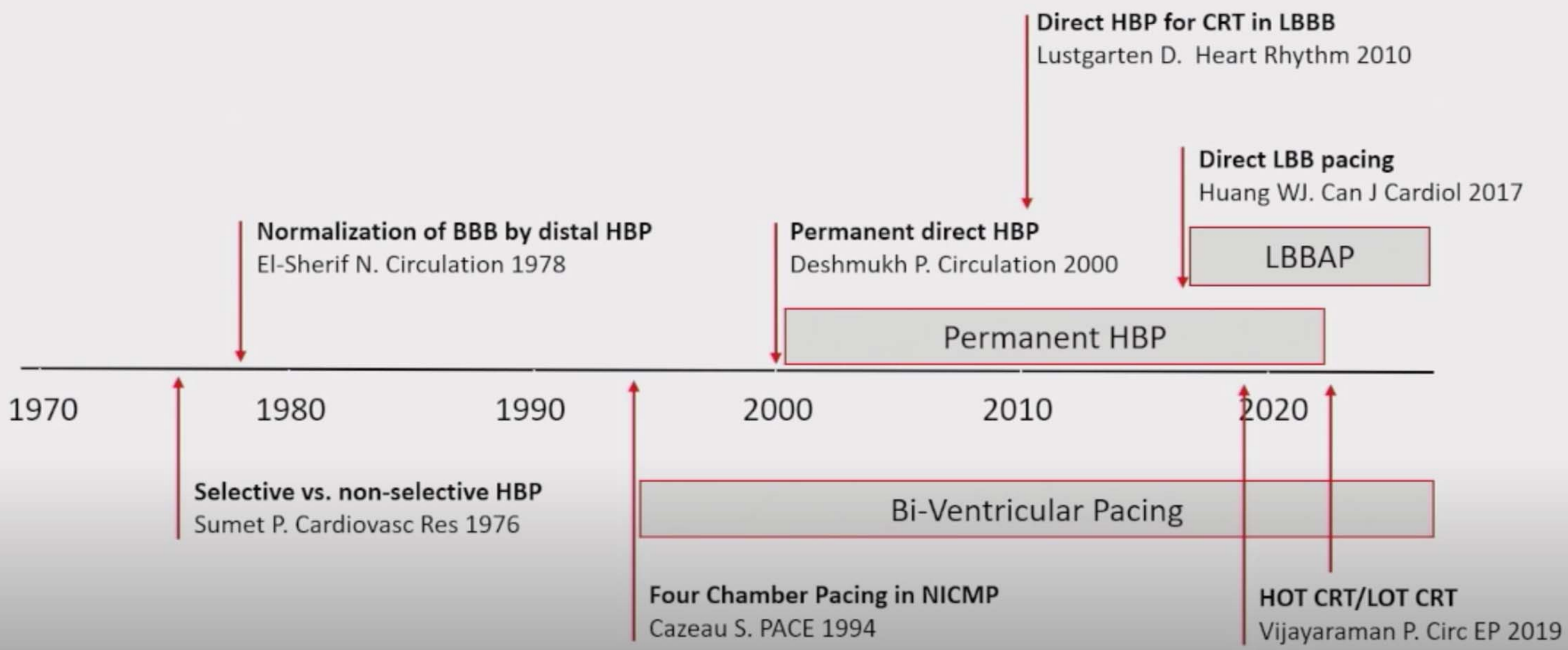


Figure 3

Comparison of mean (±SD) changes in echocardiographic left ventricular volumes and ejection fraction between baseline and follow-up values for all pacing modalities. Upper *p* value (ANOVA) determines whether differences between the means of all 3 groups are statistically significant. *p* values comparing each two groups (*t*-test) are added at the bottom. Legend: BIV: biventricular pacing; HBP: His bundle pacing; LBBP: left bundle branch pacing; LV: left ventricle; LVEDVi: left ventricular end-diastolic volume indexed to body surface area; LVESVi: left ventricular end-systolic volume indexed to body surface area.

J cardiovasc. Dev Dis 2022,9,209

Historical Timeline of CRT and CSP



Planned or ongoing studies

Larger RCTs (defined N≥100)

In planning / proposed

Recently completed

	Brady	Heart Failure				
	AVB/Pacing Indication	BLOCK HF AVB+ EF<50%	HFpEF EF≥50%	HFmEF EF 40-49%	HFrEF (EF < 40 %) Non CRT-indicated	CRT-indicated
HBP					**HOPE-HF**. His AV opt vs non-His N=198 NCT02671903	HIS-CRT for RBBB HF EF < 40%, n=120. Kutyifa/Tung
CSP	**PhysioVP-AF**. CSP vs RVP N=400 NCT05367037; **PHYSPAVB**. CSP vs RVP N=200 NCT05214365	**myPACE**. Lower HR setting vs 60bpm N=130 NCT04721314; **PACE-FIB**. CSP+AVNA vs GDMT N=334 NCT05029570			**CONSYST-CRT**. CSP vs CRT N=130 NCT05187611	**HIS-alt_2**. CSP vs CRT N=125 NCT04409119; HIS SYNC II, N=800. CSP vs. BiV for Strauss defined LBBB; **Left vs. Left CRT: CRT-P or CRT-D vs. CSP or CSP-D. N=2,136**
LBBP/ LBBAP	**LEAP-Block**. LBBP vs RVP N=458 NCT04730921; **LEAP-pilot, LEAP**. LBBAP vs RVP N=470 NCT04595487, NL9672	**RAFT-P&A**. CSP+AVNA vs CRT+AVNA N=285 NCT05428787; **OptimPacing**. LBBP vs RVP N=683 NCT04624763; **LEFT-HF**. LBBP vs RVP N=100 NCT05015660				**LEFT-BUNDLE-CRT Trial**. LBBAP vs CRT N=176 NCT05434962; **LeCaRT**. LBBAP vs CRT, N=170 NCT05365568
CSP+CRT HOTCRT LOTCRT		**HOT-CRT**. HOT/LOT CRT vs CRT N=100 NCT04561778	**RAFT-Preserved**. CSP±CRT vs CRT vs GDMT N=370) NCT04582578			**HOT-CRT**. HOT/LOT CRT vs CRT N=100 NCT04561778; **HIS-CRT**. HOTCRT vs CRT N=120 NCT05265520

Active studies posted on clinicaltrials.gov or other public trial website as of 30-AUG-2022