

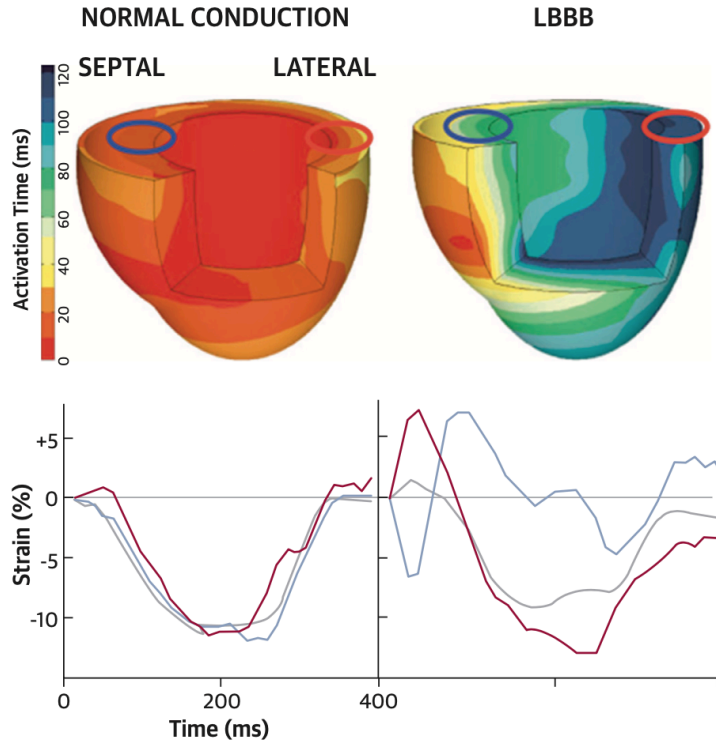
LBBAP: tecniche e nuove tecnologie...

Nuove Tecnologie per validare il pacing fisiologico

**Raimondo Calvanese
Napoli**



Mechanical Effects of LBBB



**Identificare il meccanismo della
dissincronia e correggerla**

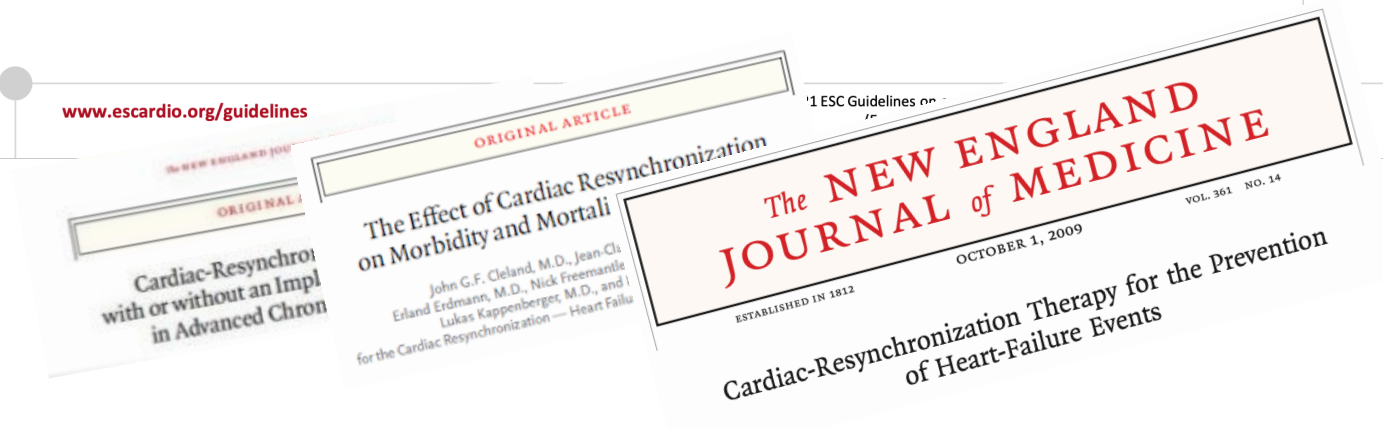
Recommendations for cardiac resynchronization therapy in patients in sinus rhythm (1)



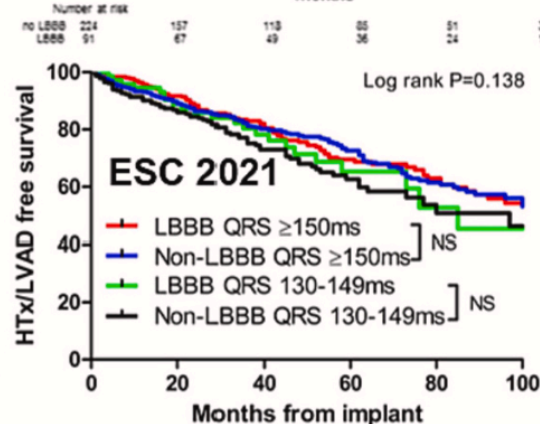
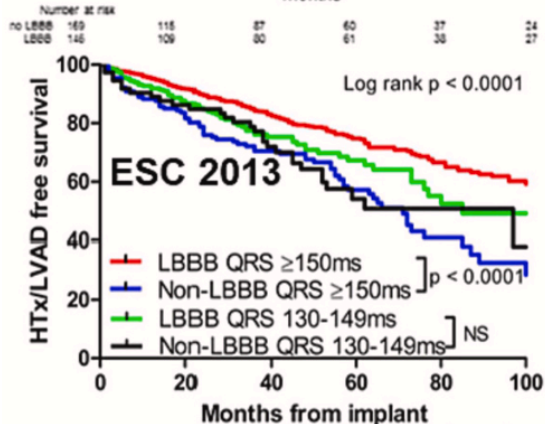
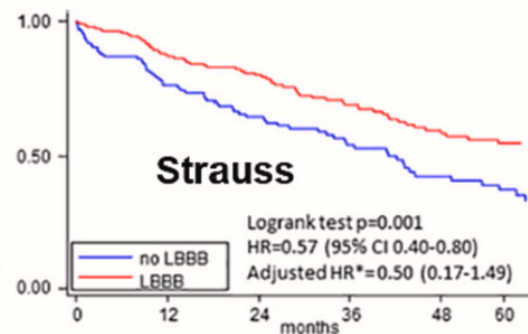
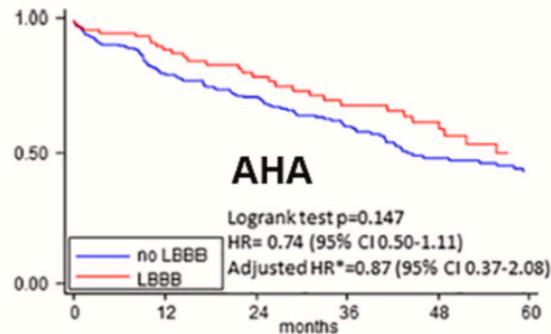
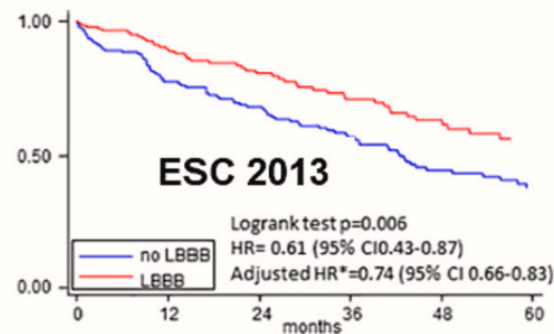
Recommendations	Class	Level
LBBB QRS morphology		
CRT is recommended for symptomatic patients with HF in SR with LVEF $\leq 35\%$, <u>QRS duration ≥ 150 ms</u> , and <u>LBBB QRS morphology</u> despite OMT, in order to improve symptoms and reduce morbidity and mortality.	I	A
CRT should be considered for symptomatic patients with HF in SR with LVEF $\leq 35\%$, QRS duration 130–149 ms, and LBBB QRS morphology despite OMT, in order to improve symptoms and reduce morbidity and mortality.	Ila	B

CRT = cardiac resynchronization therapy; HF = heart failure; LBBB = left bundle branch block; LVEF = left ventricular ejection fraction; OMT = optimal medical therapy; SR = sinus rhythm.

www.escardio.org/guidelines



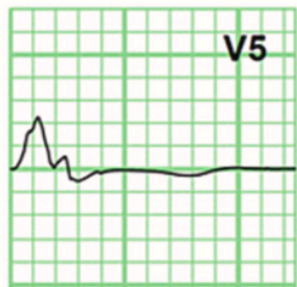
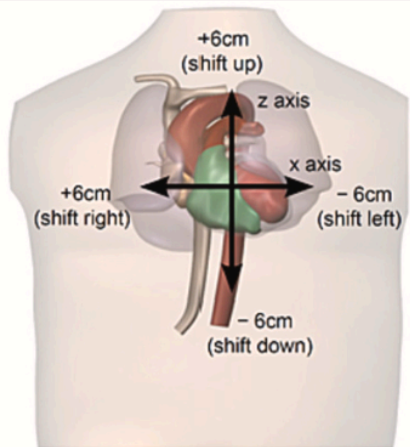
The definition of LBBB influences CRT outcome



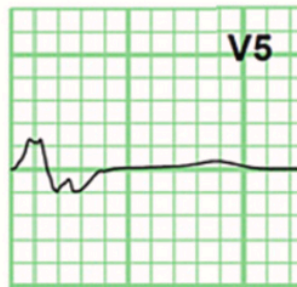
Caputo et al. Int J Card 2018.
Rijks et al. JCE 2023.



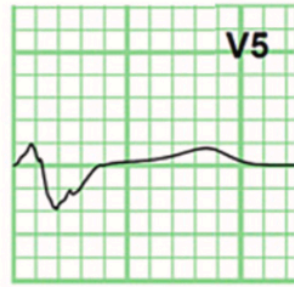
B. Heart-torso geometry affects LBBB morphology criteria



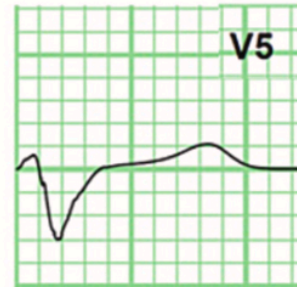
Baseline



+2 cm



+4 cm



+6 cm

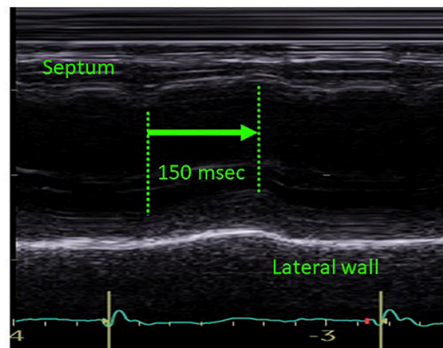
Nguyen et al. JECG 2015.



Perché abbiamo bisogno di nuove tecnologie per validare il pacing fisiologico

- True LBBB
- Non specified IVCD with more distal LV conduction disease
- There is a great diversity of both the **extent** and the **location** of conduction disorders that cause electromechanical delay
- Empirical CRT based on BiV pacing without regard to the mechanism underlying electrical dyssynchrony may not fully achieve optimal clinical outcomes.

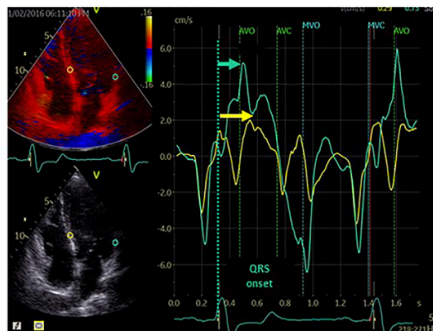
The saga of dyssynchrony imaging: Are we getting to the point



Yu's method

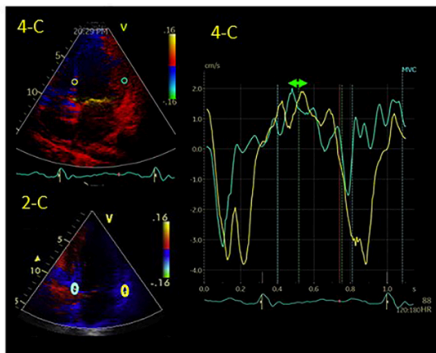
Septal-to-posterior wall motion delay calculated as the shortest interval between the maximal posterior displacement of the septum and the maximal displacement of the left posterior wall using M-mode echocardiography in short-axis view at the papillary muscle level (Ref. 15).

Pitzalis' method



Tissue Doppler Imaging signals are obtained from 4 left ventricular segments in apical 2-, 3- and 4-chamber views. The standard deviation of the time-to-peak myocardial systolic contraction is measured from the 12 left ventricular segments using the QRS onset as time reference point.

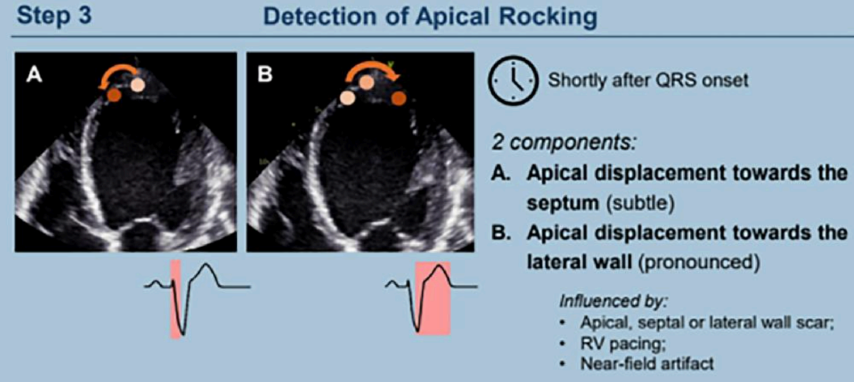
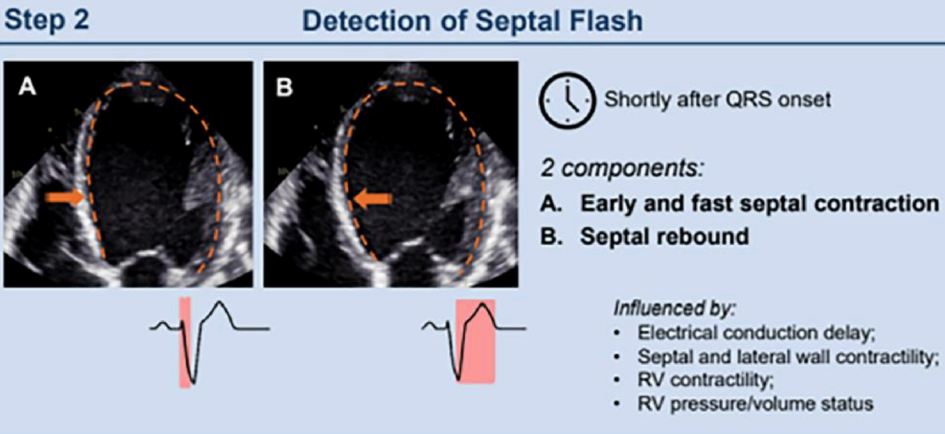
We report here the assessment of the time-to-peak contraction for the basal infero-septal (green arrow) and basal antero-septal segment (yellow arrow) (Ref 20)



Tissue Doppler signals are obtained from the apical 2- and 4-chamber view. The maximal time-to peak delay between the septum and the later wall or the anterior and posterior wall is assessed. We report here the delay between the septal and lateral wall in 4C-view. (Ref. 18, 19).

Bax's method

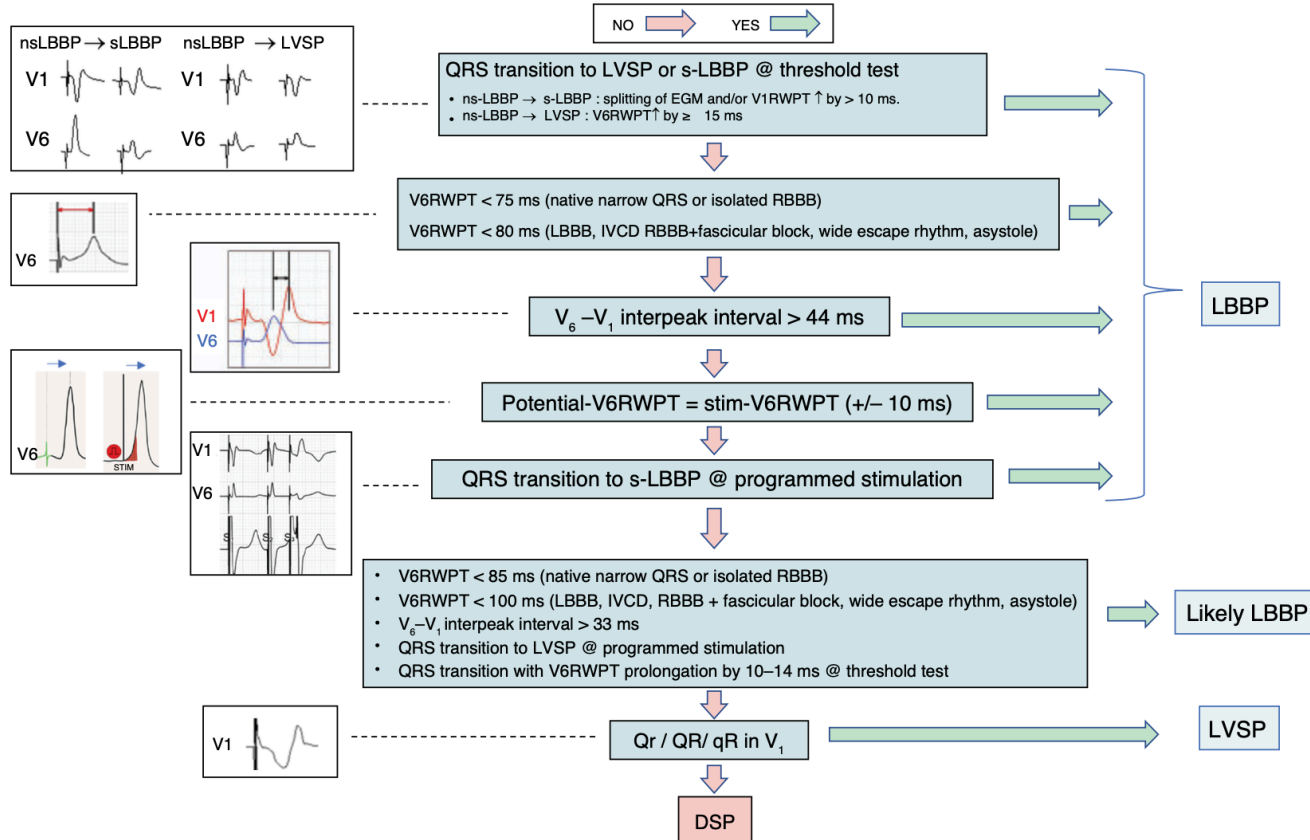
How to visually diagnose mechanical dyssynchrony in cardiac resynchronization therapy candidates using echocardiography



Step 4 **Integrative assessment**

SF	✓	+	ApRock	✗	=	Mechanical dyssynchrony	✓
SF	✗	+	ApRock	✓	=	Mechanical dyssynchrony	✓
SF	✓	+	ApRock	✓	=	Mechanical dyssynchrony	✓
SF	✗	+	ApRock	✗	=	Mechanical dyssynchrony	✗

Algorithm for confirming conduction system capture with LBBAP



Limitation of conventional pacing assessment methods

LBBAP without a terminal r'/R'-wave in V1

- **Rapid transseptal activation**
- **Slow propagation via diseased LBB**
(resulting in simultaneous biventricular activation, probably the dominant mechanism **in patients with HF**)
- **Anodal capture** with bipolar pacing
- **Fusion** with intrinsic conduction

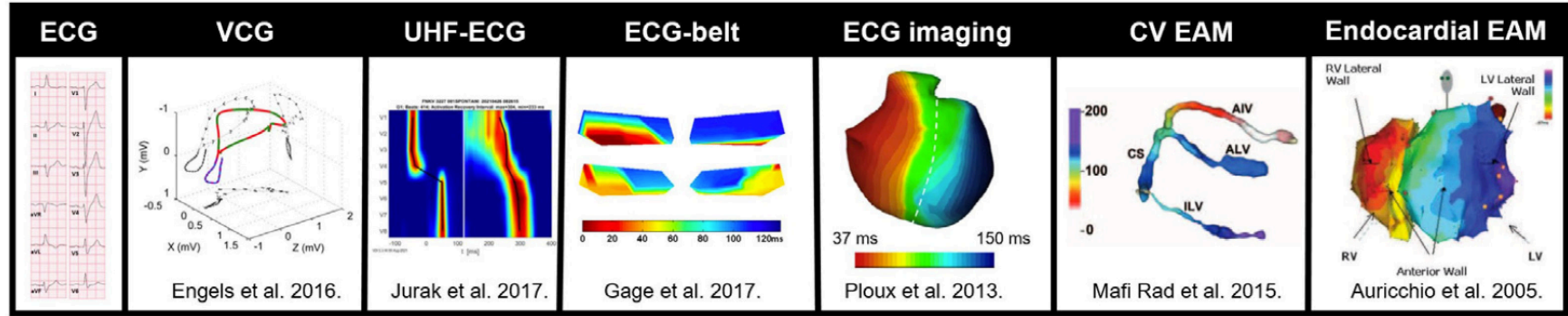
V6RWPT

The accuracy of RWPT is uncertain:

- in pts with **low septal and/or apical lead placements: V6RWPT shortening** and **V6–V1 interpeak interval prolongation** without CS capture and misclassification of LVSP as LBBP;
- V6RWPT depends upon heart size and conduction velocity (e.g. with misclassification of LBBP as LVSP due to long V6RWPT in patients with slow conduction or dilated hearts).

None of the **V6RWPT** (or **V6–V1 interpeak**) cut-offs
are **100% accurate** for CS capture and
there is little information on the optimal cut-offs in patients with HF.

Methods of Ventricular dyssynchrony Assessment



Non-invasive

Invasive

SYSTEM UHF

- Simple to use 14-lead ECG
- Easy to interpret
- Real-time

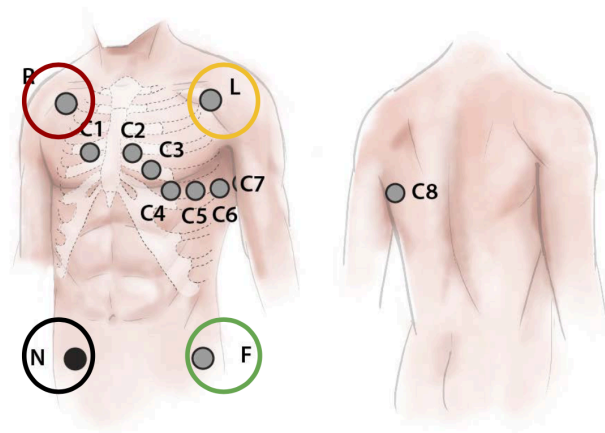
The UHF-ECG (Ultra High Frequency Electrocardiogram) is an evolution of the traditional ECG that enables the analysis of the heart's electrical activation with much higher resolution.

Unlike conventional ECG, which operates at lower frequencies, **UHF-ECG analyzes frequency components above 500 Hz**, allowing for:

- More precise detection of ventricular dyssynchrony.
- Optimization of pacemaker lead placement.
- Improvement of cardiac resynchronization therapy (CRT).¹

Noninvasive assessment of electrical ventricular dyssynchrony

Electrode placement



standard-ECG



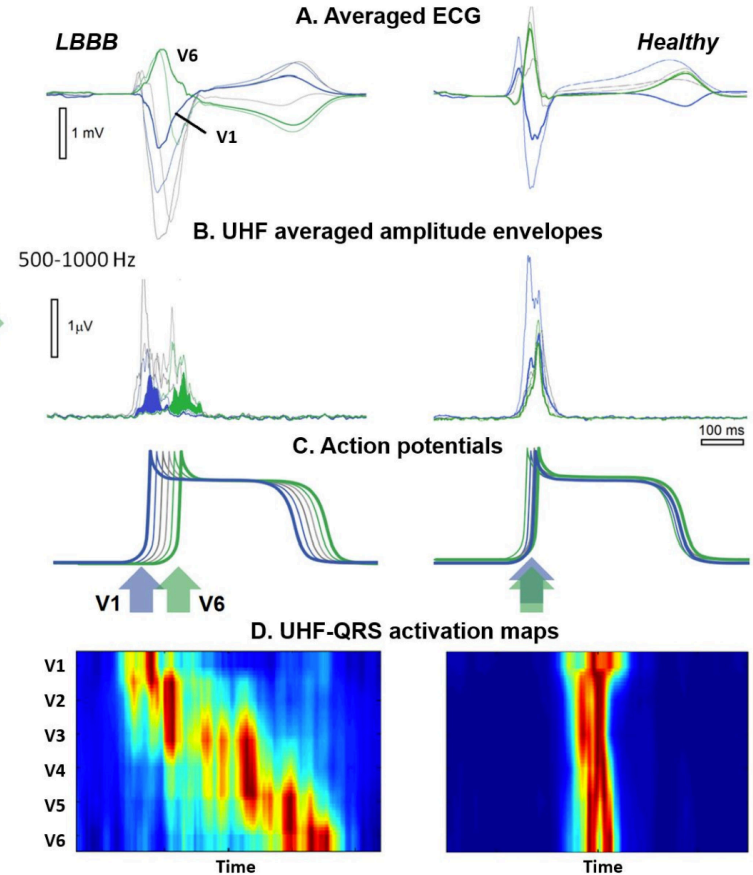
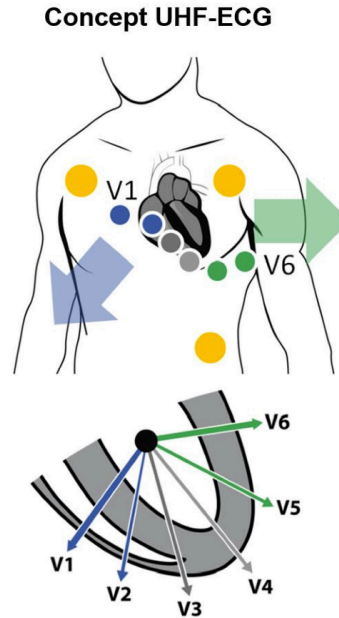
- **P wave** typically falls within the range of **5–30 Hz** (reflecting an atrial propagation velocity of **~1 m/s**),
- **QRS complex** spans **5–50 Hz** (corresponding to a His–Purkinje system propagation velocity of **1–4 m/s**)
- **T wave** is predominantly found within the **0–10 Hz** range, indicating a relatively slow repolarization spread

UHF-ECG

- **High-frequency notching** has been associated with the presence of **patchy fibrosis** in the necropsies of patients after myocardial infarction.
- **High- frequency components** may already manifest during **ischemia**. The presence of high-frequency components (150–250 Hz) was observed in canine studies after inducing ischemia;
- **The existence of high-frequency components up to 700 Hz in the QRS complex has been concordantly associated with ventricular Enlargement, Hpertrophy, and Mocardial Scar;**
- **High-frequency components** (particularly above 70 Hz) were also observed by the group of Josephson in endocardial electrograms and associated with reentrant ventricular tachycardia;
- **The signal-averaged ECG method** was introduced, employing a bandpass of **40–250 Hz** to detect late ventricular potentials.

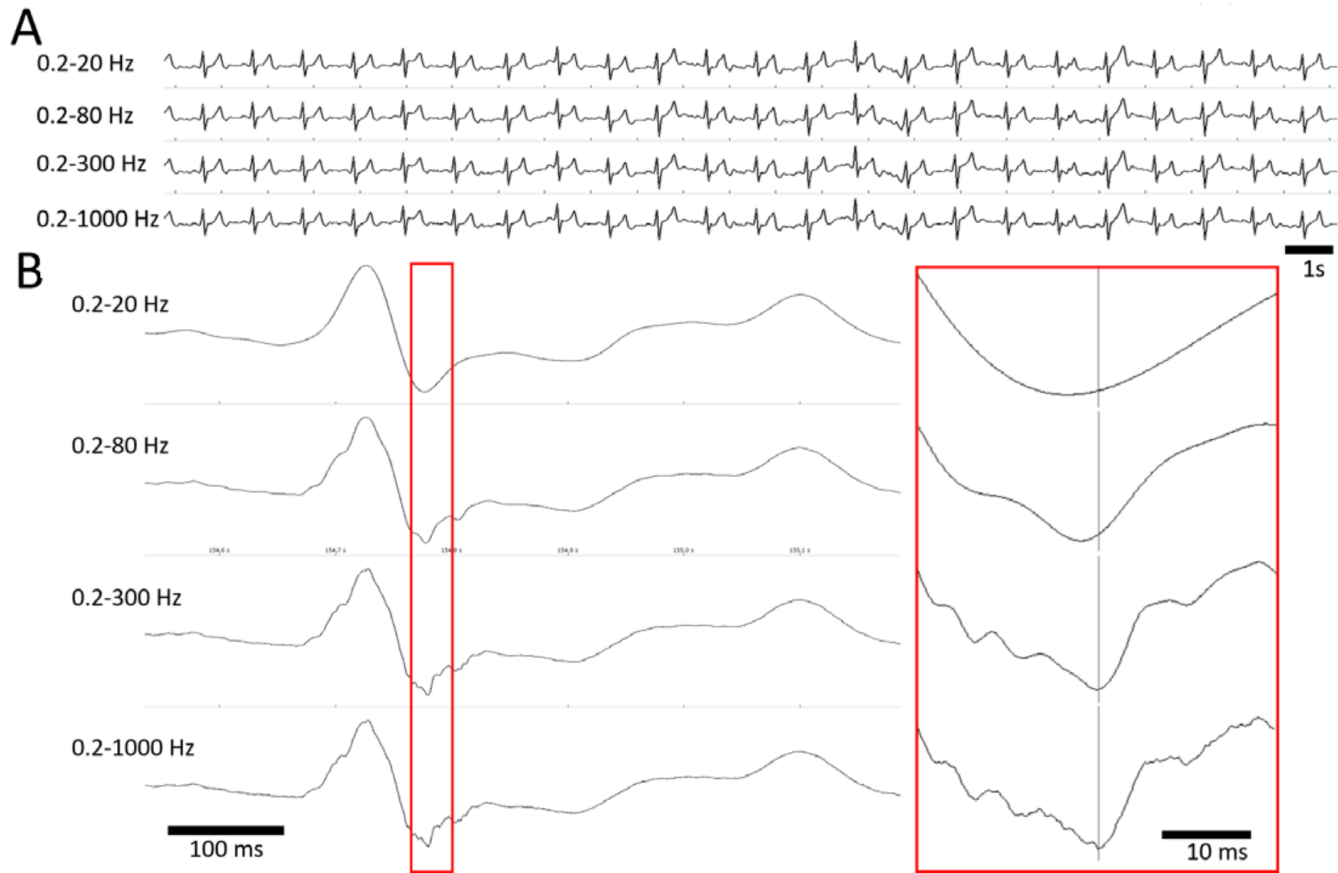
UHF-ECG

- Local activation
- Intramural activation



UHF-ECG principle

- ECG 0.1-40 Hz
- Fragmentation up to 100 Hz
- Late potentials 40-250 Hz
- High-Frequency 150-250 Hz
- **Ultra-High-Frequency 150-1500 Hz**



UHF-ECG processing

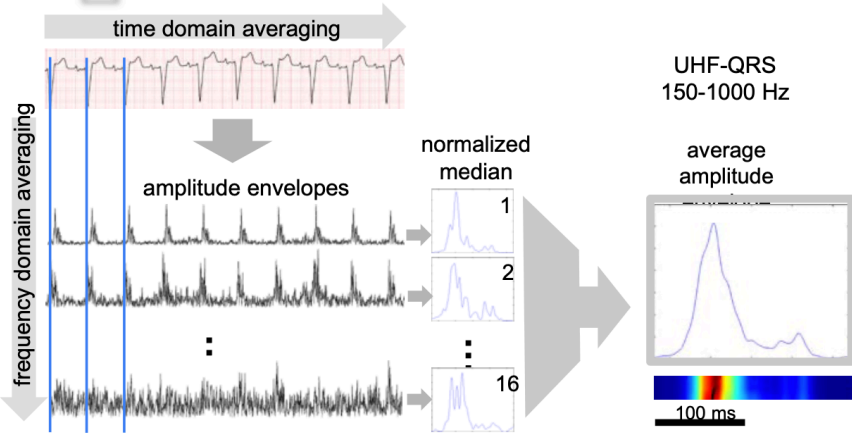
V1 lead



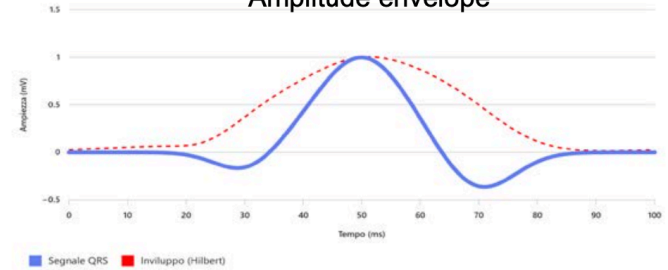
- QRS detection
- QRS categorization - morphological groups
- 16 frequency bands, median, normalization
- averaging over frequencies

16 frequency bands

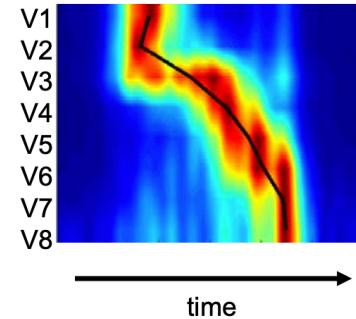
H
Z
1: 150-250
2: 200-300
⋮
16: 900-1000



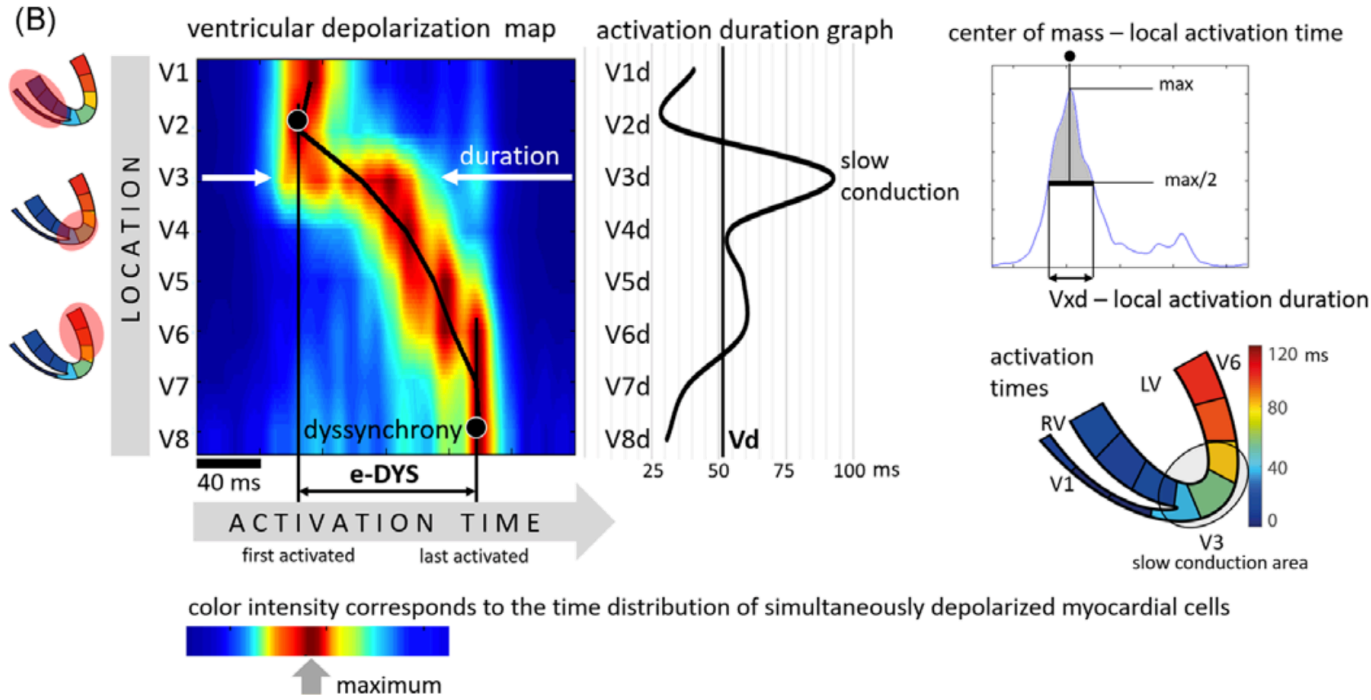
Amplitude envelope



ventricular depolarization map



UHF-ECG

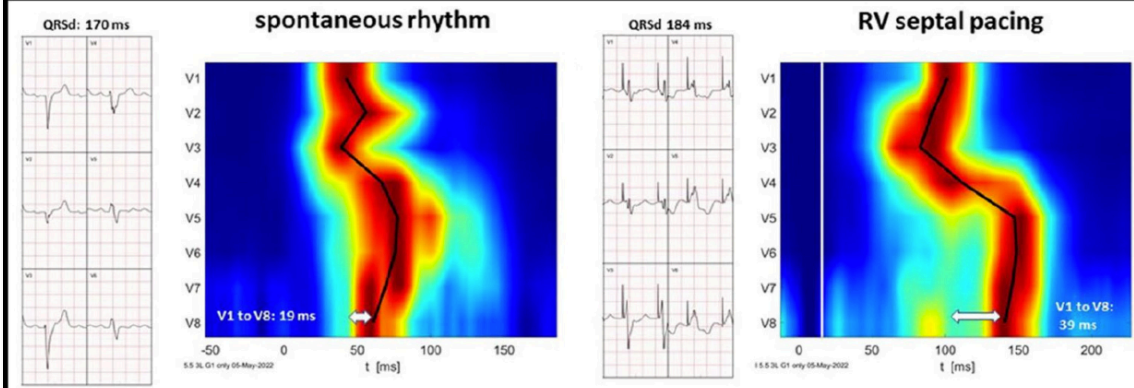


Jurak P, et al. Novel ultra-high-frequency electrocardiogram tool for the description of the ventricular depolarization pattern before and during cardiac resynchronization. J Cardiovasc Electrophysiol. 2020 Jan;31(1):300-307.

UHF-ECG

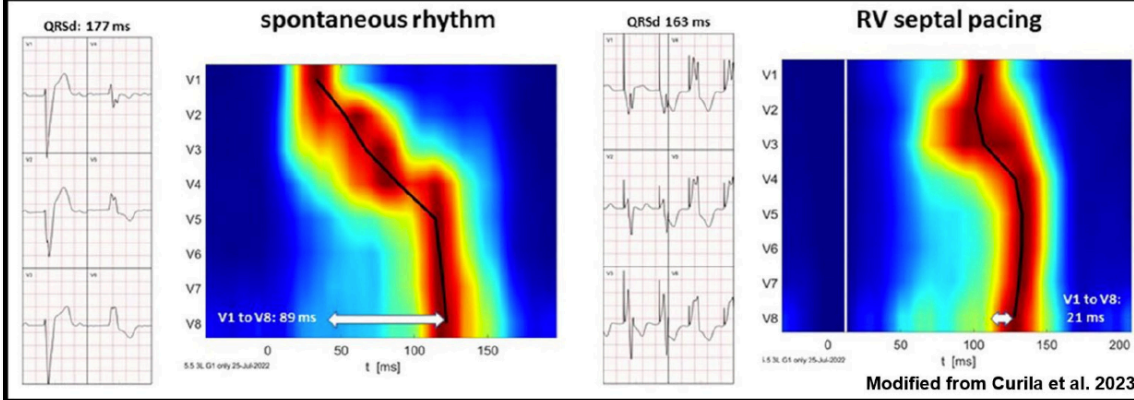
Is it a true left bundle branch block or not?

IVCD patient

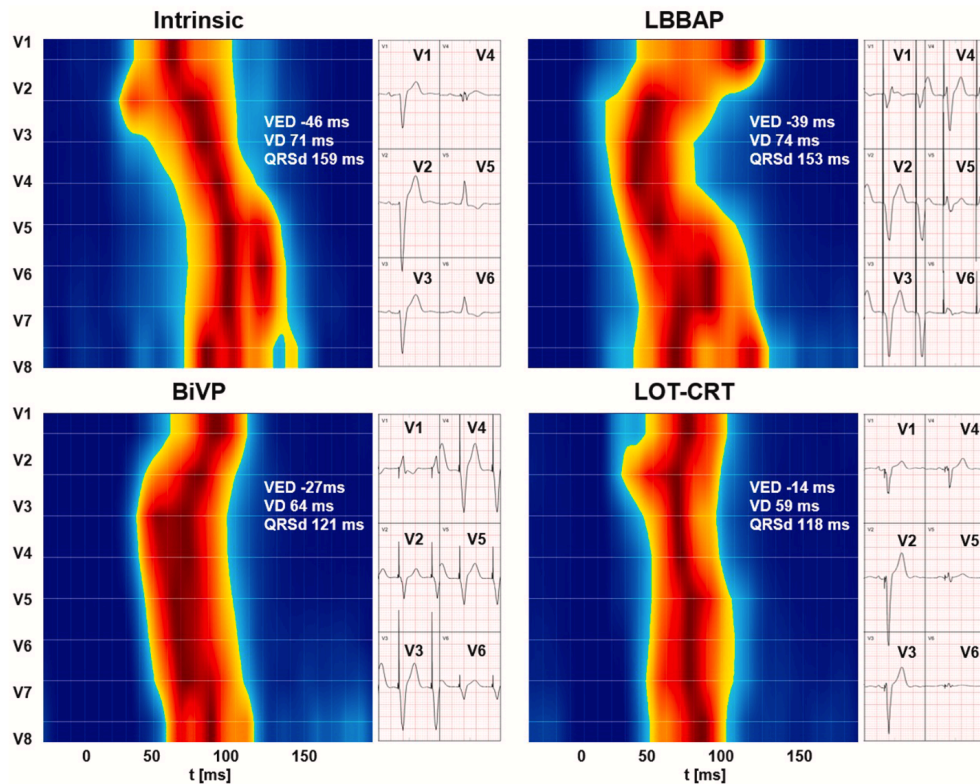


Selezione dei pazienti

LBBB patient



Patient with an ambiguous electrocardiogram

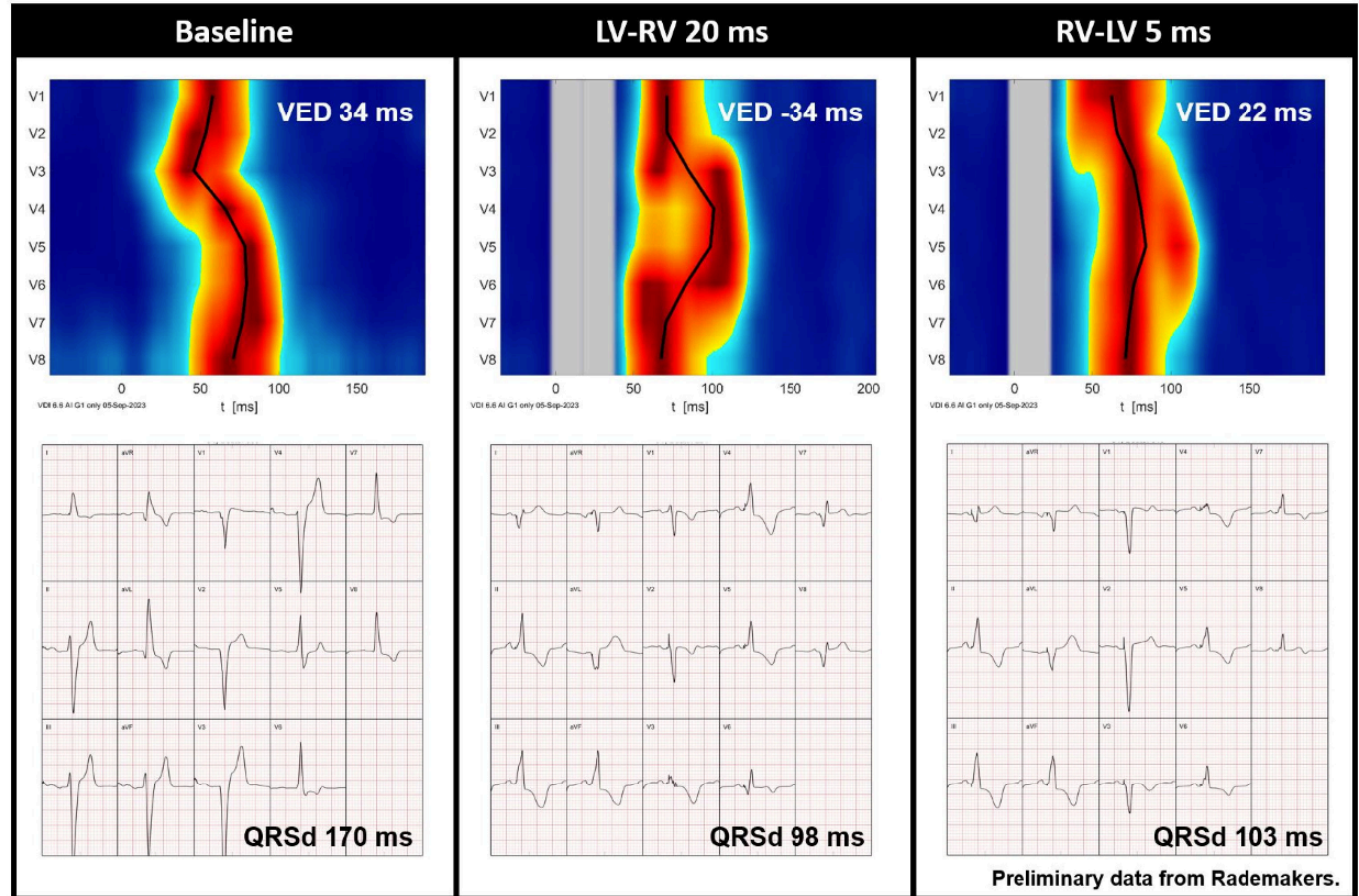


The baseline ECG showed a QRS duration (QRSd) of 159 ms, QS complex in V1, broad and predominantly monophasic R waves in the lateral leads, and discordant T waves.

This ambiguous morphology could be compatible with LBBB according to the 2013 ESC criteria, although it does not clearly fulfill the 2021 ESC or Strauss definitions owing to the absence of distinct mid-QRS notching.

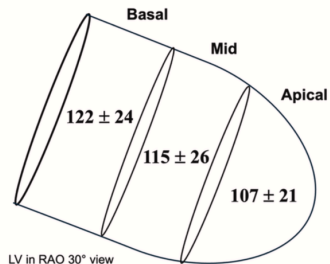


Ottimizzazione CRT

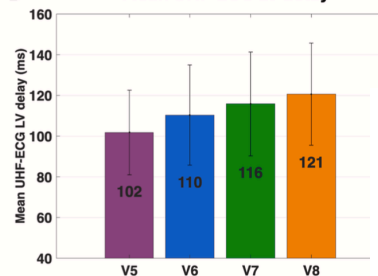


Non-invasive assessment of left ventricular activation delay for identifying cardiac resynchronization therapy responders using ultra-high-frequency electrocardiogram ^e

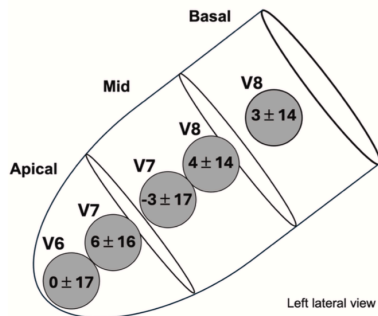
A Mean QLV in each LV segment



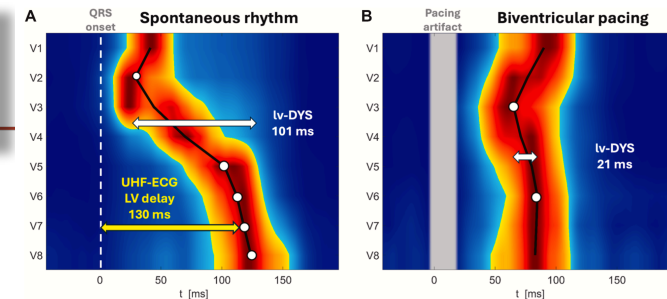
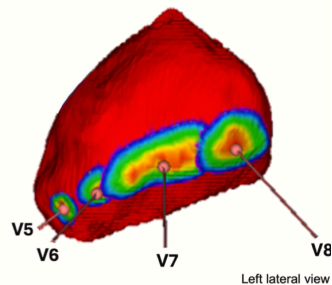
B Mean UHF-ECG LV delay



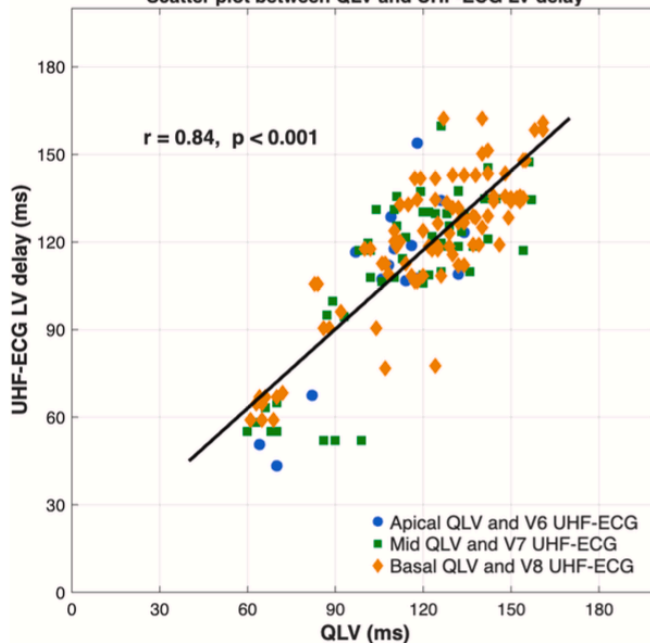
C Mean difference between invasive QLV and UHF-ECG LV delay



D MR image of LV free wall with UHF-ECG leads projections



Scatter plot between QLV and UHF-ECG LV delay

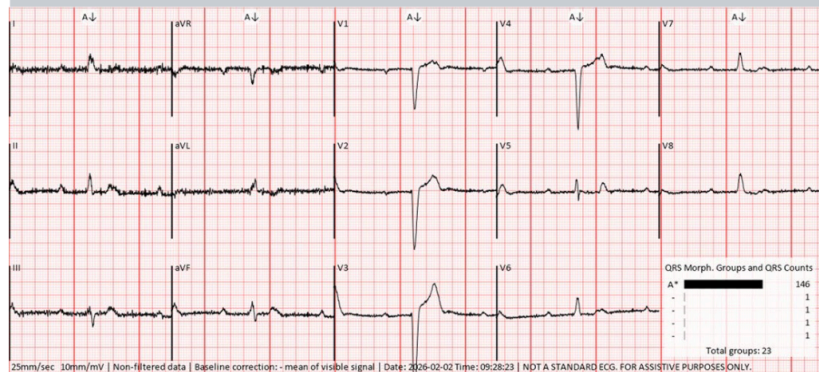


- The invasively acquired QLV can be reliably assessed non-invasively using UHF-ECG.
- In pts with a shorter QLV and lv-DYS (below 95 ms and 60 ms, respectively), biventricular CRT did not reduce LV dyssynchrony.

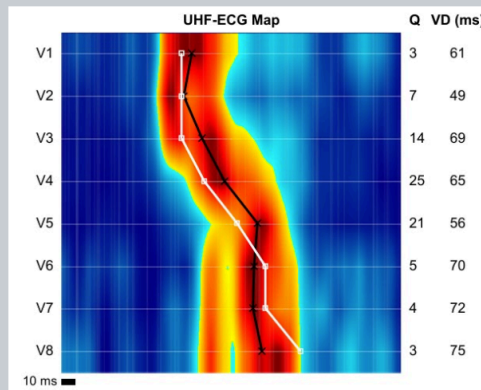


- Male, 78 years of age
- II° grade and complete AVB
- Baseline QRS – BBSX 130 ms
- Baseline EF: 55%
- Indications for PM DR CSP

INTRINSIC



VDI IMAGE

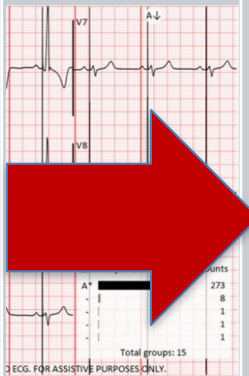
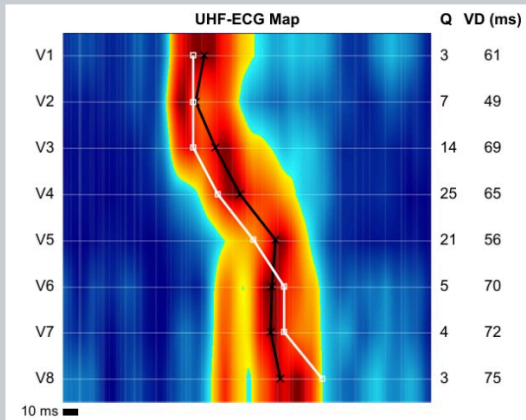


VDI RESULT

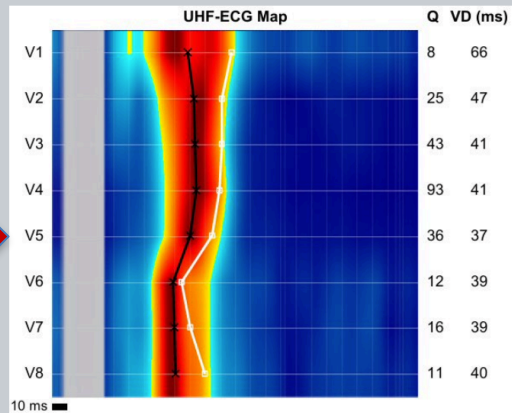
Automated Results

VED16	52 ms
MeanVD16	62 ms
VED18	55 ms
MeanVD18	65 ms
QRS (total)	168x
QRS (major)	146x , label A, 86.9%
Two-peak ptn	(none)

VDI IMAGE



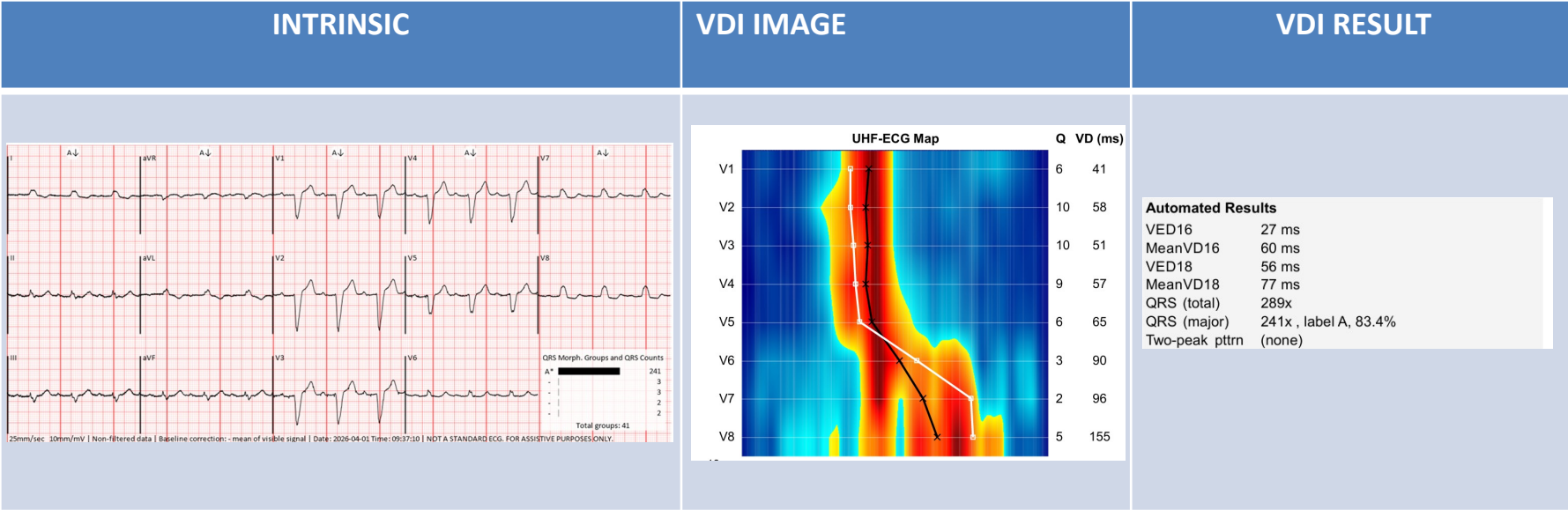
VDI IMAGE



VDI RESULT

Automated Results

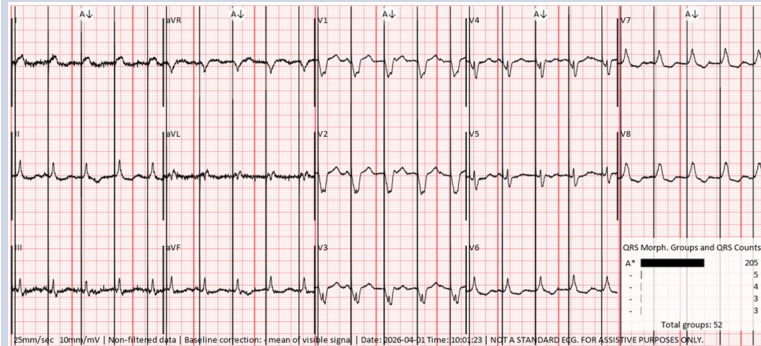
VED16 -15 ms
 MeanVD16 45 ms
 VED18 -15 ms
 MeanVD18 44 ms
 QRS (total) 294x
 QRS (major) 273x , label A, 92.9%
 Two-peak pttrn (none)



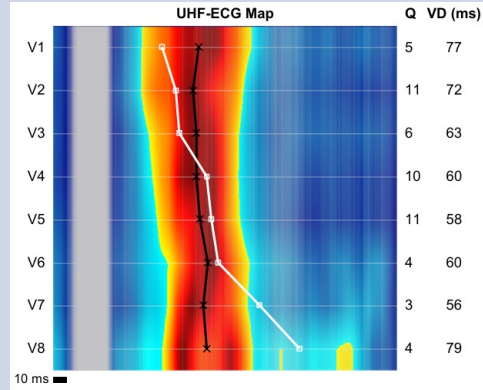
- FEMALE
- 73 YEARS OF AGE
- BASELINE QRS: AVB I SYMPTOMATIC - BBSX 160 MS
- BASELINE EF: 50%
- INDICATIONS FOR PM DR CSP

Case Report 2 – VDI LBBP

VVI 100 bpm



VDI IMAGE



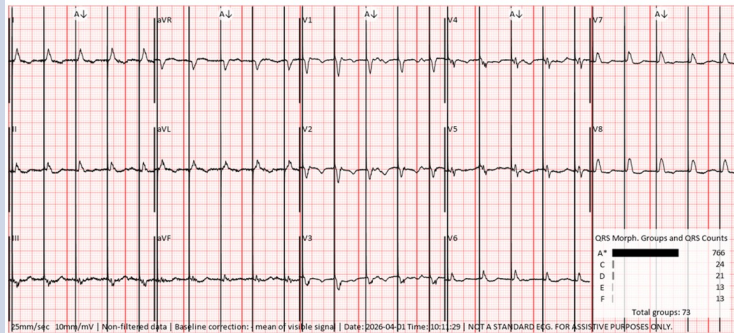
VDI RESULT

Automated Results

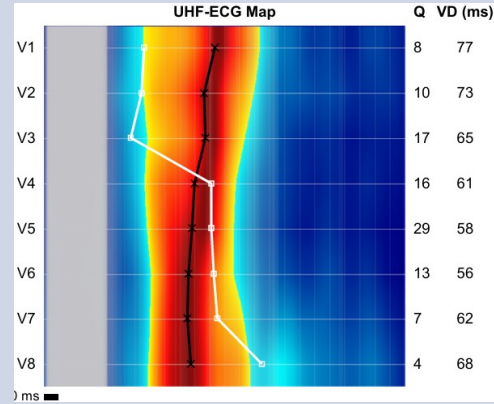
VED16	11 ms
MeanVD16	65 ms
VED18	11 ms
MeanVD18	66 ms
QRS (total)	272x
QRS (major)	205x , label A, 75.4%
Two-peak ptrn	(none)

Case Report 2 – VDI LBBP

VVI 100 bpm



VDI IMAGE



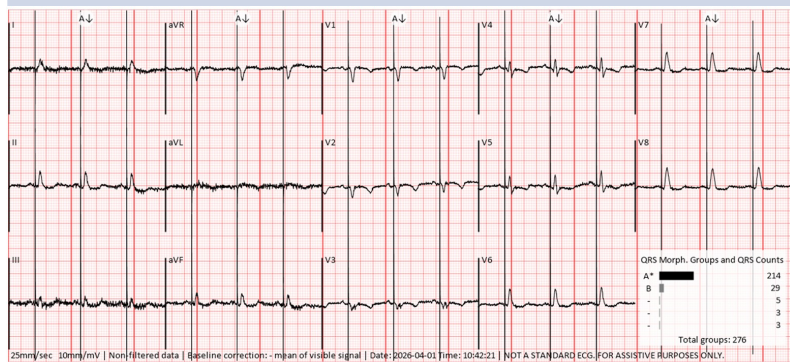
VDI RESULT

Automated Results

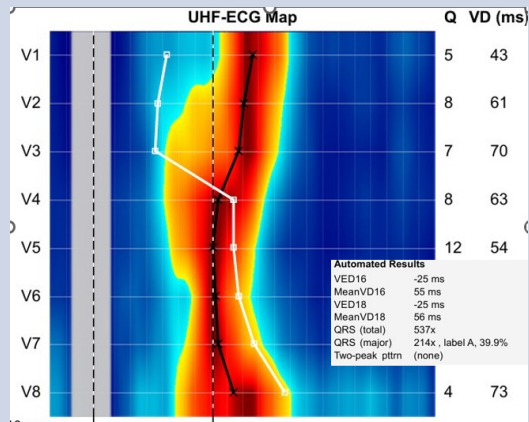
VED16	-18 ms
MeanVD16	65 ms
VED18	-18 ms
MeanVD18	65 ms
QRS (total)	938x
QRS (major)	766x , label A, 81.7%
Two-peak pttrn	(none)

Case Report 2– VDI LBBP

FINAL EKG



VDI IMAGE



VDI RESULT

Automated Results

VED16 -25 ms
MeanVD16 55 ms
VED18 -25 ms
MeanVD18 56 ms
QRS (total) 537x
QRS (major) 214x, label A, 39.9%
Two-peak pttm (none)

Beyond QRS Narrowing: left bundle branch area pacing enhances ventricular synchrony and myocardial work



Global myocardial work index (GMWI) and efficiency

- In this pilot study a significant association was observed between reduced VDI index and increased EF highlighting the physiological benefits of LBBAP.
- Pre-implant VDI may also assist in selecting patients most likely to benefit from a tailored, physiology-based pacing strategy.

Conclusioni

- UHF apre nuove prospettive per la valutazione della dissincronia
- Selezione dei pazienti
- Valutazione/Ottimizzazione della correzione della dissincronia
- Semplificare procedura di impianto
- Approccio «tailored» (CSP, CRT, LOT CRT...) in relazione al disturbo di conduzione (true LBBB/IVCD)



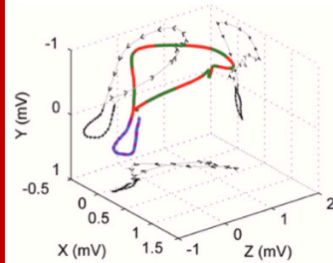
UHF-ECG

- **Einthoven** noted that “an EKG recorded with a galvanometer, with a deflection time of about 0.01 s, does not practically differ from the same EKG recorded with a galvanometer with an infinitely small deflection time”.
- This suggests that frequencies greater than 100 Hz have negligible contributions to the ECG signal
- While it therefore may be justifiable to use the commercial frequency range of <150 Hz in normal individuals, the presence of higher frequencies has been linked to ventricular pathologies.

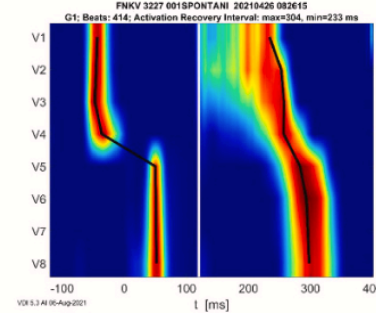
Methods of Ventricular dyssynchrony Assessment

Electrocardiography

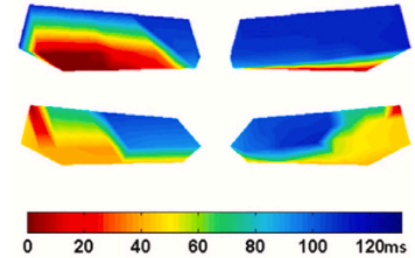
VCG



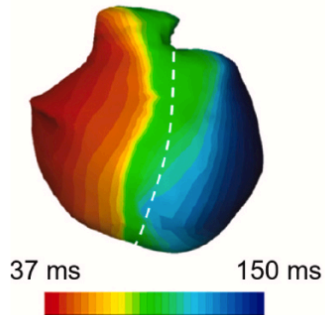
UHF-ECG



ECG-belt



ECG imaging



**Intra-cardiac
measurements**

UHF-ECG

- **High-frequency notching** has been associated with the presence of **patchy fibrosis**;
- **High- frequency components** may manifest during **ischemia**;
- **The existence of high-frequency components up to 700 Hz in the QRS complex has been concordantly associated with ventricular Enlargement, Hypertrophy, and Myocardial Scar**;
- **High-frequency components** (particularly above 70 Hz) were also observed in endocardial electrograms and associated with **reentrant ventricular tachycardia**;
- **The signal-averaged ECG method** was introduced, employing a bandpass of **40–250 Hz** to detect **late ventricular potentials**.

Case Report – VDI LBBP

PROGRAMMING

-
-
-
-
-
-
-

DDD – 140/110ms
Unipolar configuration
QRS: 125 ms

VDI RESULTS - INTRINSIC

Automated Results

VED16	27 ms
MeanVD16	60 ms
VED18	56 ms
MeanVD18	77 ms
QRS (total)	289x
QRS (major)	241x , label A, 83.4%
Two-peak pttm	(none)

VDI FINAL RESULTS

Automated Results

VED16	-25 ms
MeanVD16	55 ms
VED18	-25 ms
MeanVD18	56 ms
QRS (total)	537x
QRS (major)	214x , label A, 39.9%
Two-peak pttm	(none)



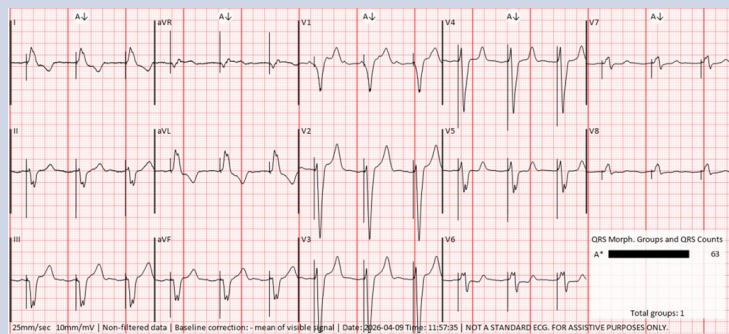
- INNOVATIVE SOLUTIONS PILOT

Patient characteristics

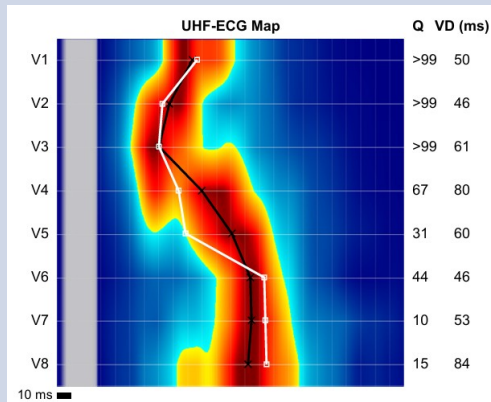
- Male
- 69 years of age
- ICM and CMD
- Pacemaker dependent with a PMK DR
- Baseline EF: 35%
- Indications for upg to CRT-D

Case Report 3 – VDI LBBP

RV APEX PACING



VDI IMAGE



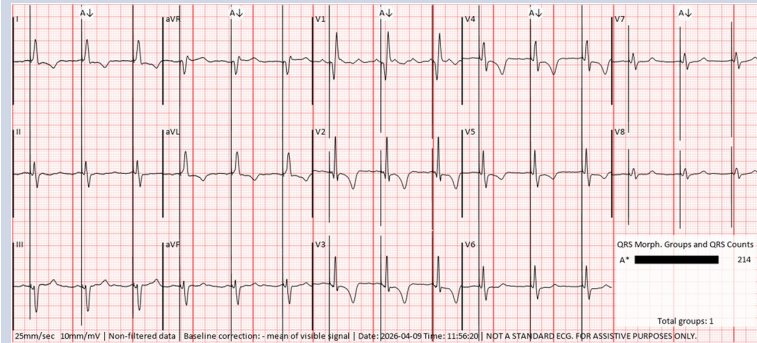
VDI RESULT

Automated Results

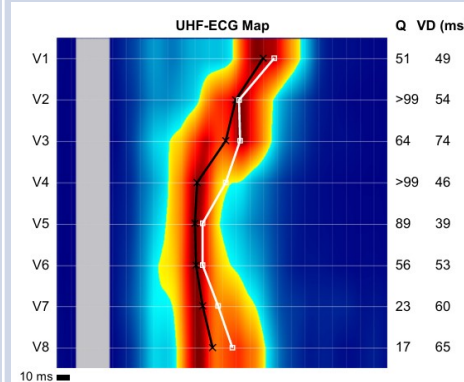
VED16	62 ms
MeanVD16	57 ms
VED18	64 ms
MeanVD18	60 ms
QRS (total)	63x
QRS (major)	63x , label A, 100.0%
Two-peak ptnr	(none)

Case Report 3 – VDI LBBP

LV tip - COIL



VDI IMAGE



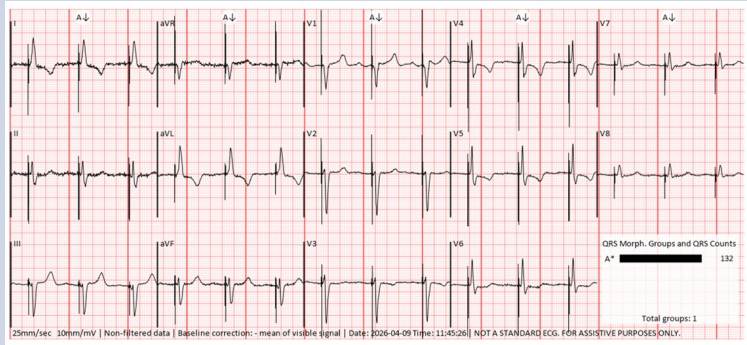
VDI RESULT

Automated Results

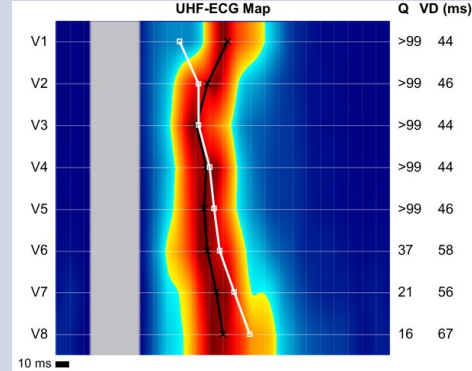
VED16	-50 ms
MeanVD16	53 ms
VED18	-50 ms
MeanVD18	55 ms
QRS (total)	214x
QRS (major)	214x , label A, 100.0%
Two-peak pttm	(none)

Case Report 3– VDI LBBP

BIPOLAR



VDI IMAGE



VDI RESULT

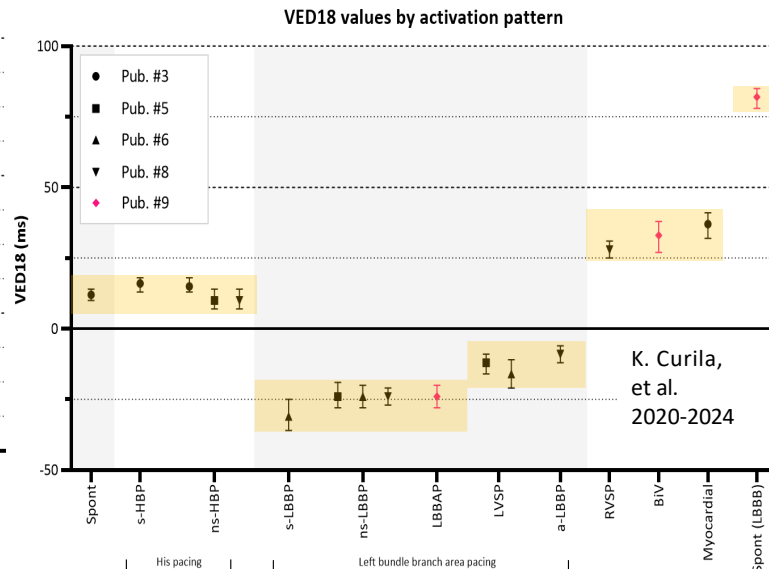
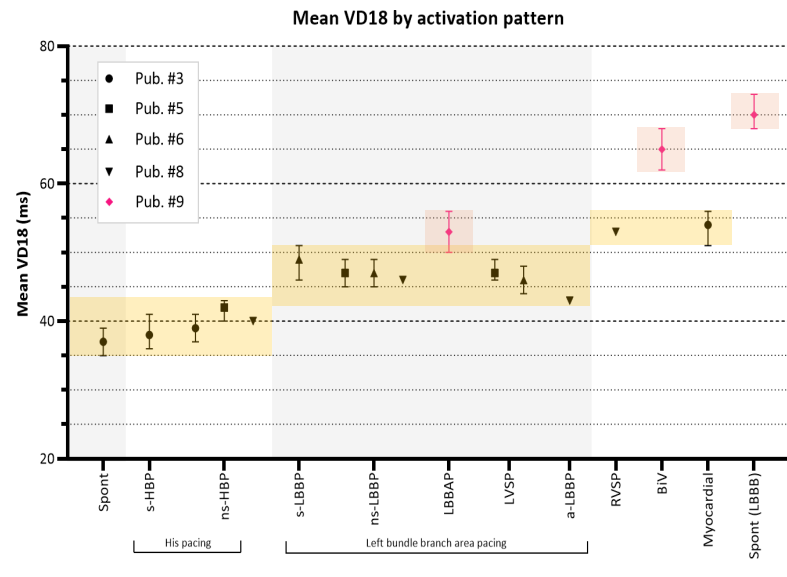
Automated Results

VED16	-22 ms
MeanVD16	47 ms
VED18	-22 ms
MeanVD18	51 ms
QRS (total)	132x
QRS (major)	132x , label A, 100.0%
Two-peak ptn	(none)

Case Report – VDI LBBP

PROGRAMMING	VDI RESULTS - INTRINSIC	VDI FINAL RESULTS																												
• • • • • • • DDD – 160/140ms LV tip - RVc configuration QRS: 120 ms	Automated Results <table><tr><td>VED16</td><td>62 ms</td></tr><tr><td>MeanVD16</td><td>57 ms</td></tr><tr><td>VED18</td><td>64 ms</td></tr><tr><td>MeanVD18</td><td>60 ms</td></tr><tr><td>QRS (total)</td><td>63x</td></tr><tr><td>QRS (major)</td><td>63x , label A, 100.0%</td></tr><tr><td>Two-peak pptrn</td><td>(none)</td></tr></table>	VED16	62 ms	MeanVD16	57 ms	VED18	64 ms	MeanVD18	60 ms	QRS (total)	63x	QRS (major)	63x , label A, 100.0%	Two-peak pptrn	(none)	Automated Results <table><tr><td>VED16</td><td>-50 ms</td></tr><tr><td>MeanVD16</td><td>53 ms</td></tr><tr><td>VED18</td><td>-50 ms</td></tr><tr><td>MeanVD18</td><td>55 ms</td></tr><tr><td>QRS (total)</td><td>214x</td></tr><tr><td>QRS (major)</td><td>214x , label A, 100.0%</td></tr><tr><td>Two-peak pptrn</td><td>(none)</td></tr></table>	VED16	-50 ms	MeanVD16	53 ms	VED18	-50 ms	MeanVD18	55 ms	QRS (total)	214x	QRS (major)	214x , label A, 100.0%	Two-peak pptrn	(none)
VED16	62 ms																													
MeanVD16	57 ms																													
VED18	64 ms																													
MeanVD18	60 ms																													
QRS (total)	63x																													
QRS (major)	63x , label A, 100.0%																													
Two-peak pptrn	(none)																													
VED16	-50 ms																													
MeanVD16	53 ms																													
VED18	-50 ms																													
MeanVD18	55 ms																													
QRS (total)	214x																													
QRS (major)	214x , label A, 100.0%																													
Two-peak pptrn	(none)																													

UHF-ECG local activation duration VD



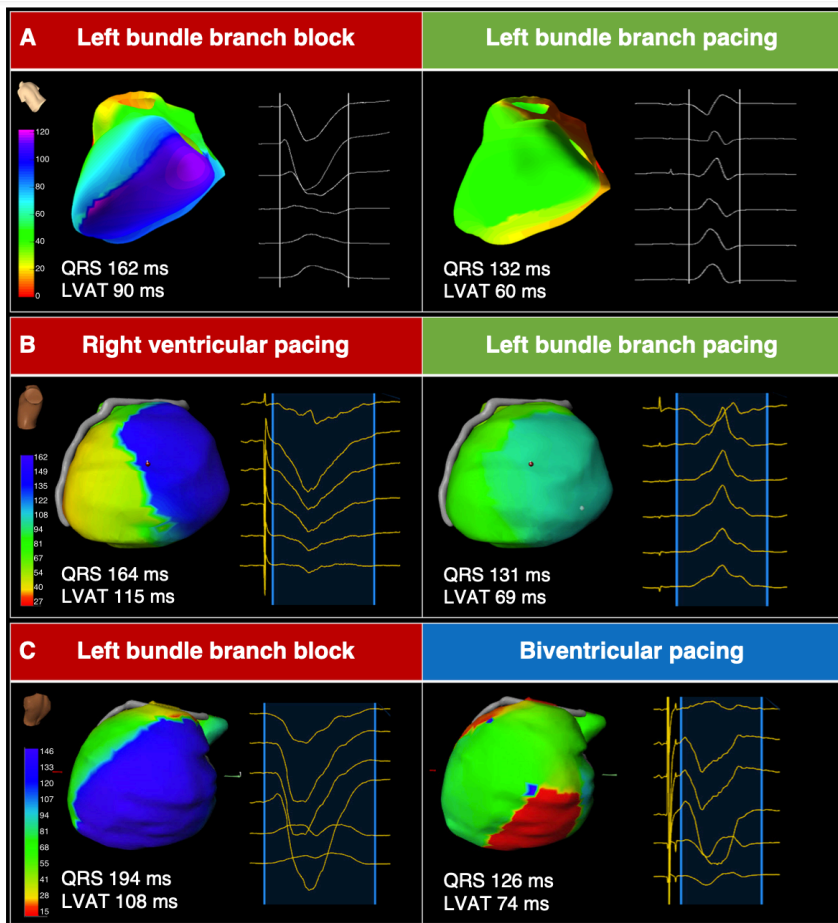
K. Curila,
et al.
2020-2024

Brady



HF





PROGRAMMING

- DDD – 160/140ms
- Unipolar configuration
 - QRS: 112 ms

VDI RESULTS - INTRINSIC

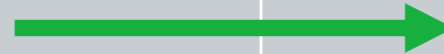
Automated Results

VED16	52 ms
MeanVD16	62 ms
VED18	55 ms
MeanVD18	65 ms
QRS (total)	168x
QRS (major)	146x , label A, 86.9%
Two-peak pptrn	(none)

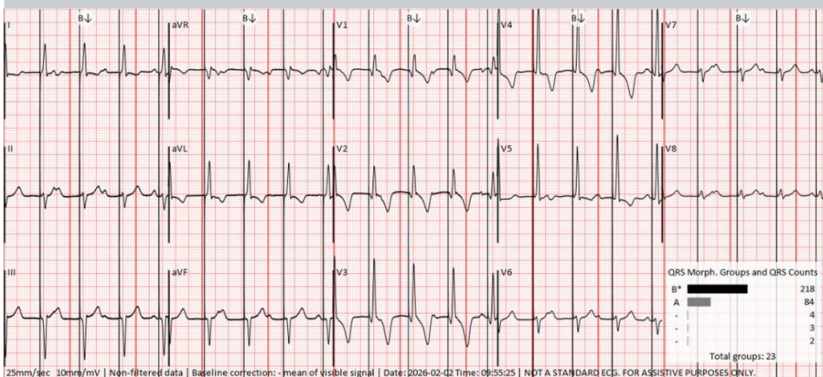
VDI FINAL RESULTS

Automated Results

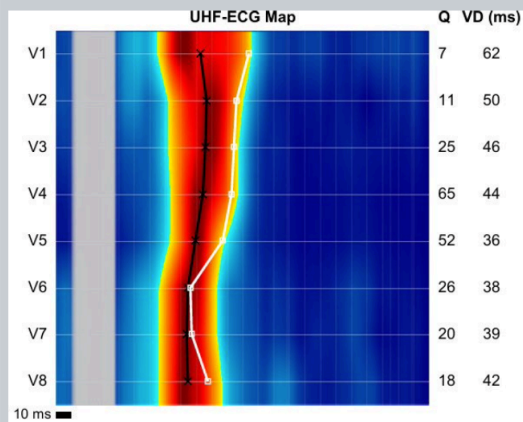
VED16	-15 ms
MeanVD16	45 ms
VED18	-15 ms
MeanVD18	44 ms
QRS (total)	294x
QRS (major)	273x , label A, 92.9%
Two-peak pptrn	(none)



VVI 100 bpm



VDI IMAGE

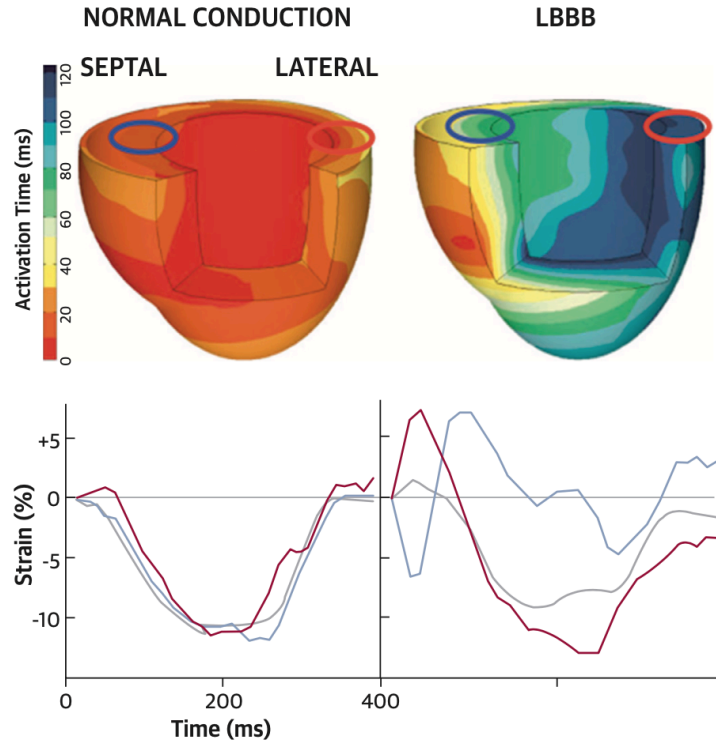


VDI RESULT

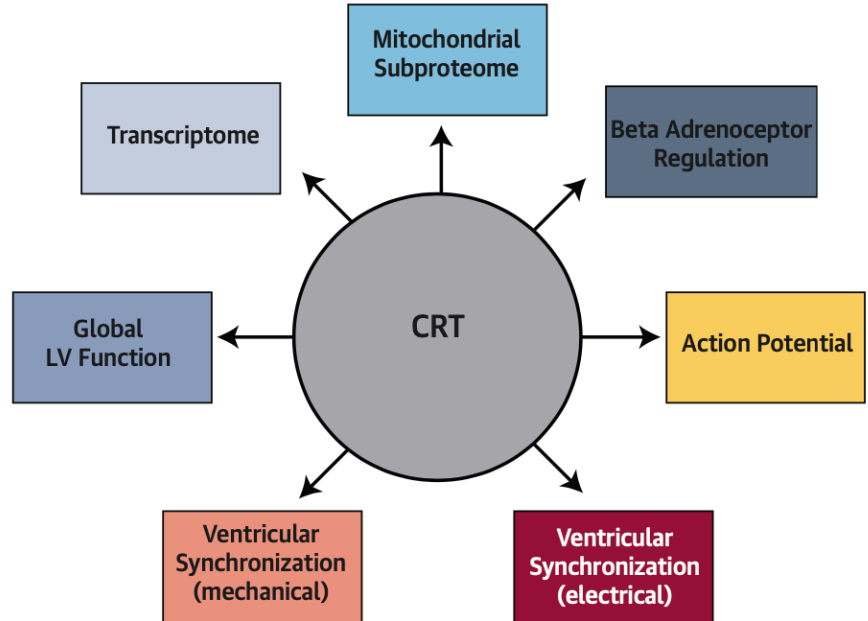
Automated Results

VED16	-12 ms
MeanVD16	46 ms
VED18	-12 ms
MeanVD18	45 ms
QRS (total)	332x
QRS (major)	218x , label B, 65.7%
Two-peak pttm	(none)

Mechanical Effects of LBBB

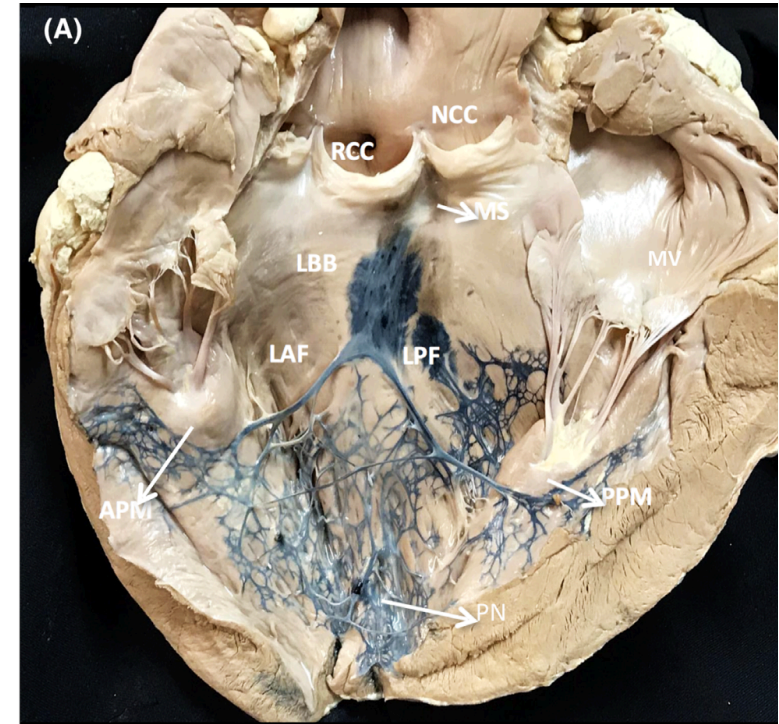
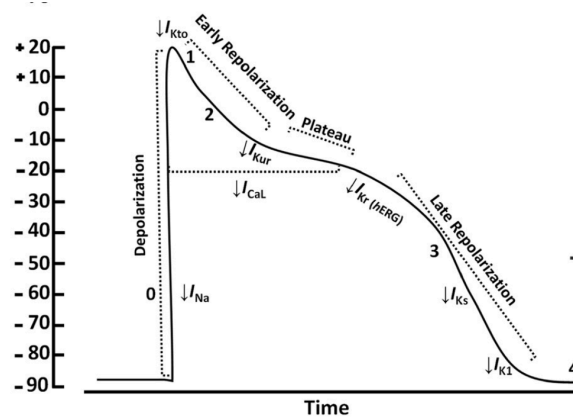
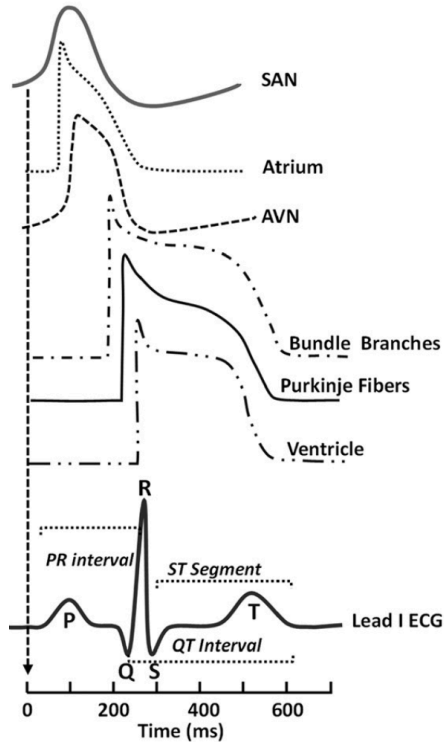


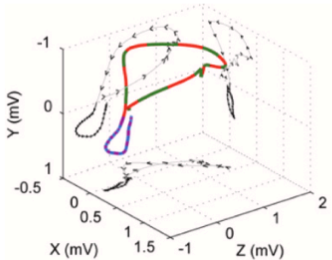
Effects of CRT



Purkinje system

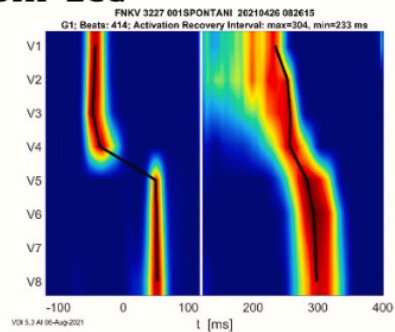
- PA con elevata velocità dell'upstroke
- Alto Vmax; Plateau ampio
- Lunga durata del PA > alta refrattarietà
- Potenziale diastolico massimo con maggiore negatività
- Presenza di CX43



Technique	Advantages	Disadvantages	Key parameters
VCG 	Reconstructed from the standard ECG.	No real-time application.	QRS area (25-28, 32, 65) QRST area (27, 29) T area (31)



UHF-ECG



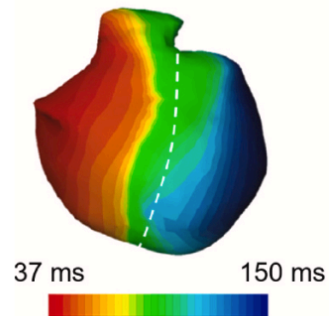
Real-time computation and 2D visualization.
Incorporate time and frequency domain.

Specialized acquisition system with 8 precordial electrodes.

e-DYS (ventricular electrical delay) (34, 35, 38, 45)



ECG imaging

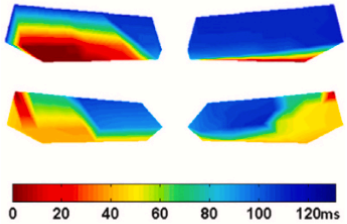


High-resolution.
 3D visualization.

Specialized acquisition system
 with ~200 electrodes.
 Geometrical information from
 CT or MRI.

VEU (ventricular
 electrical uncoupling)
 (55, 56)
 ADV (activation delay
 vector) (58)



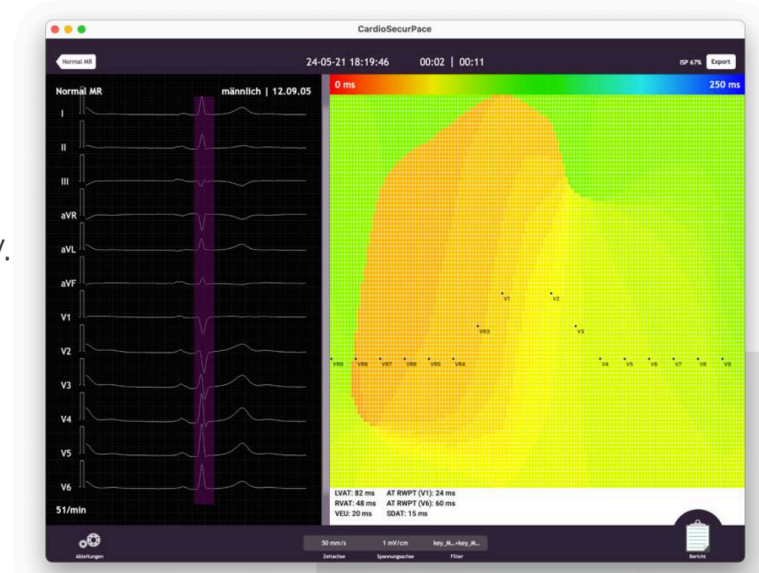
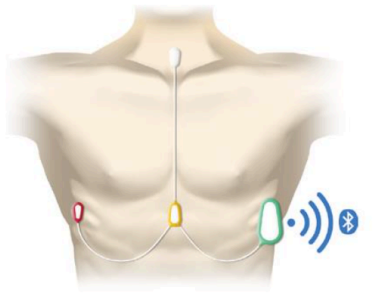
ECG-belt 	Real-time computation and 2D visualization. Incorporate time domain.	Specialized acquisition system with ~50 electrodes.	SDAT (standard deviation of activation times) (46-48, 50)
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Intra-cardiac measurements	Derived from existing CRT leads.	Can only be measured post-implantation (invasive).	Q-LV (60) Q-LV minus Q-RV (61-63)
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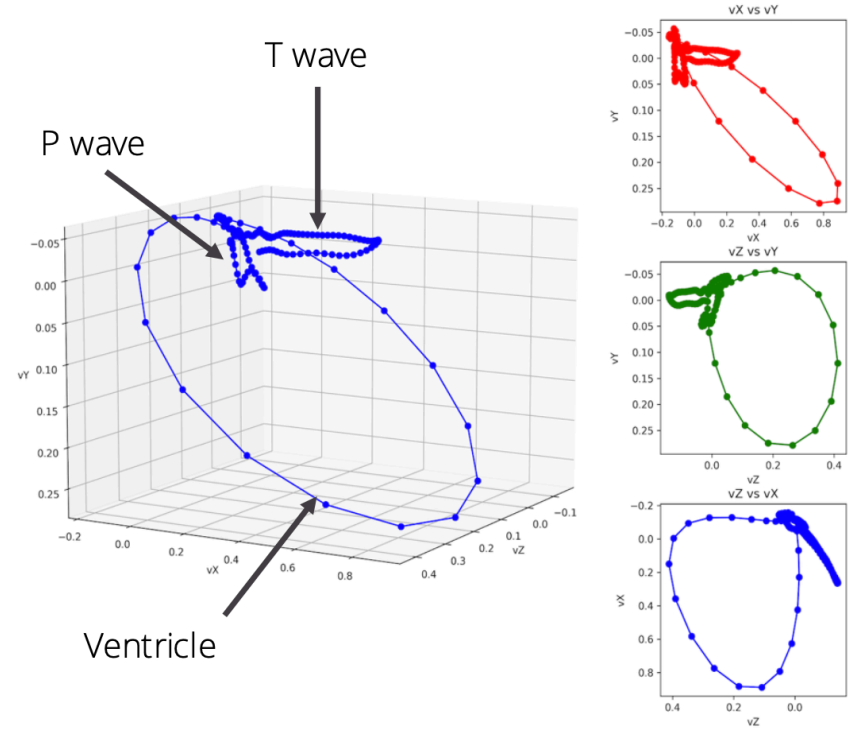


- Visualization of real-time cardiac activation time
- resolution exceeding 14,000 leads,
- utilizing only 4 electrodes,
- technology based on Frank's (1960's) vectorcardiography.

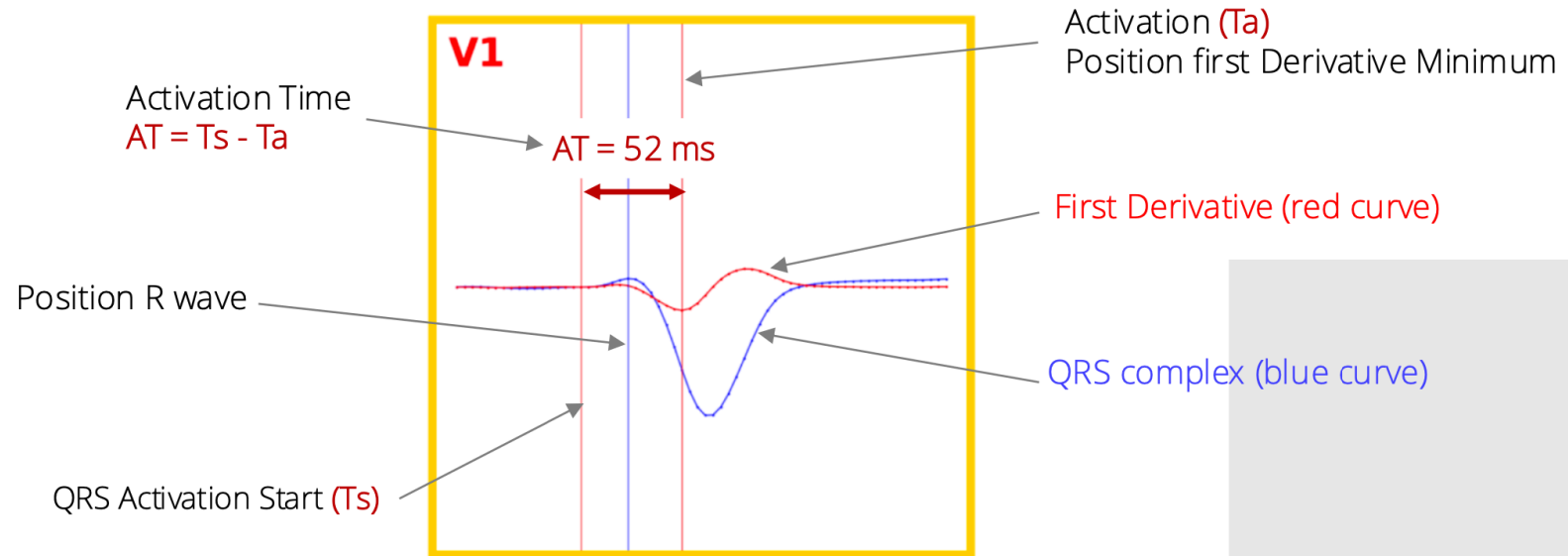


Activation map of a healthy heart

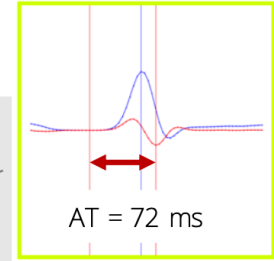
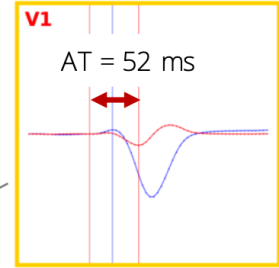
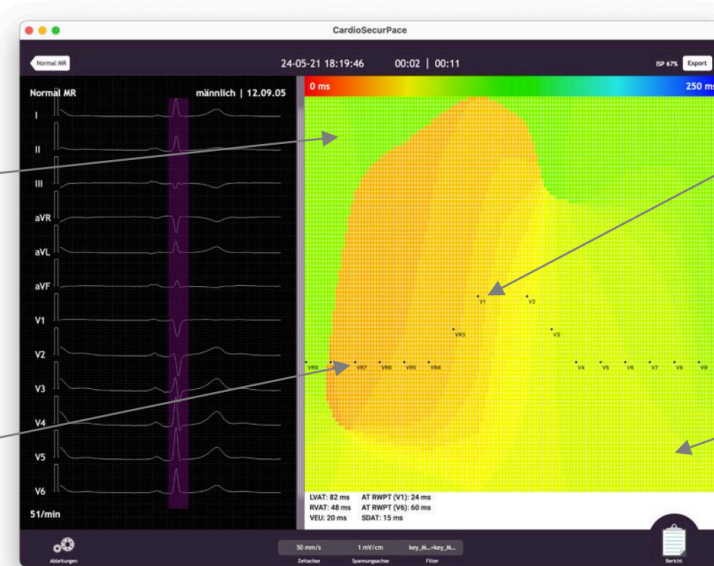
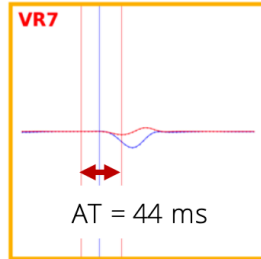
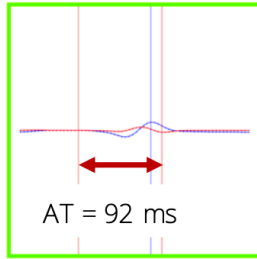
- The electrical potentials are represented in a 3-dimensional vector that rotates beat by beat forming a loop.
- 3 loop components: P wave, T wave, Ventricle.
- Frank's technology encapsulates all cardiac electrical activity within the vector.
- A standard 12-lead ECG is reconstructed from the vector loop (Dower 1988).
- CardioSecur extrapolates the vector loop data generating over 14,000 leads in real time.



Activation time = the time corresponding to the minimum value of the first derivative of the QRS complex.



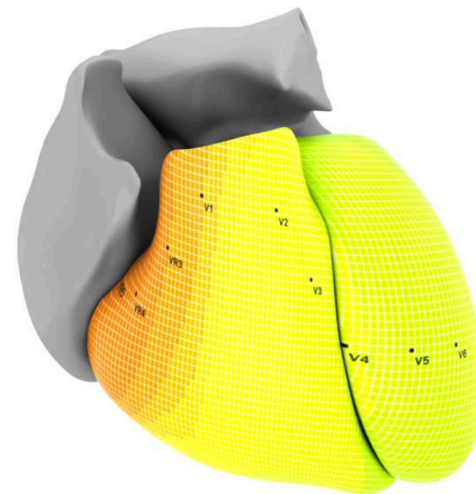
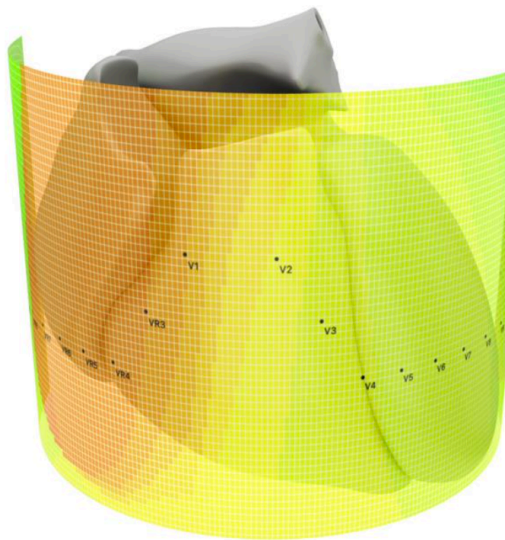
Activation Time (AT) is computed for every directional vector relative to the heart, displayed in a color-coded system.



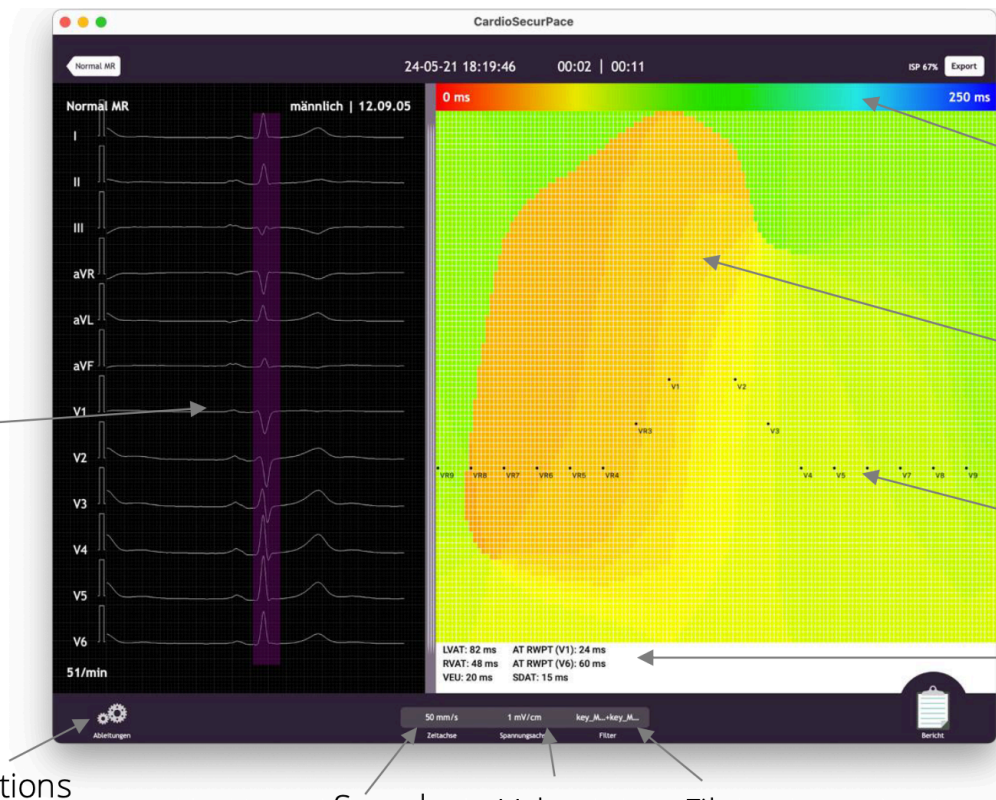
0 ms

250 ms

Color Code of the Activation Time



Moving the activation map from 2D to 3D



12-lead ECG

Color scheme

Map

Conventional leads for orientation

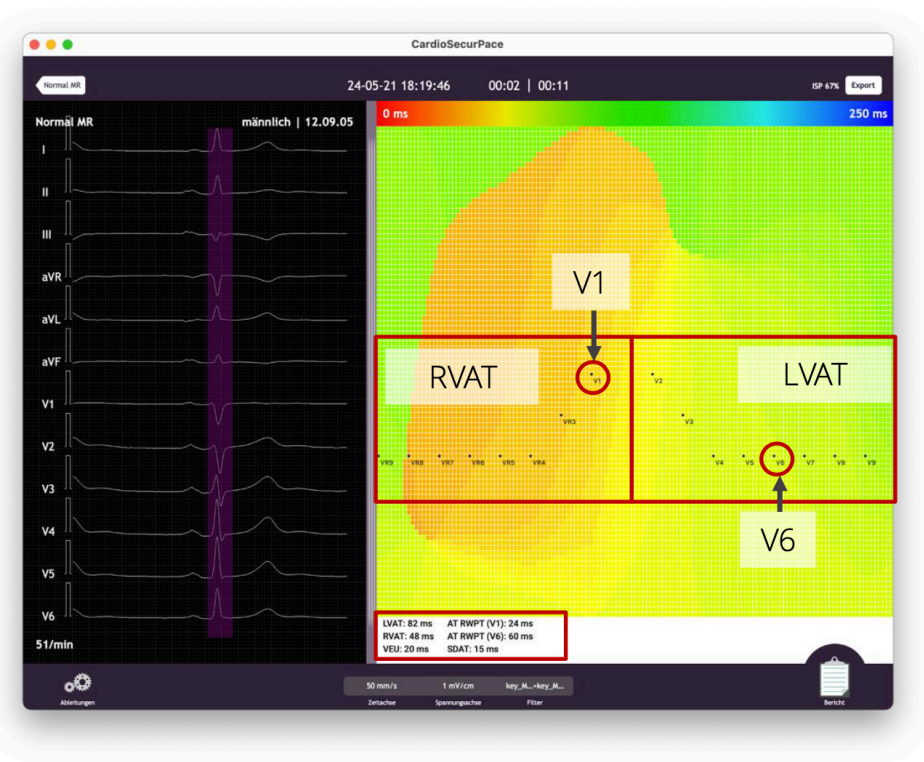
Parameters

Lead options

Speed

Voltage

Filters



LVAT
RVAT
SDAT

Left Ventricle Activation Time
Right Ventricle Activation Time
Standard deviation of LVAT and RVAT combined

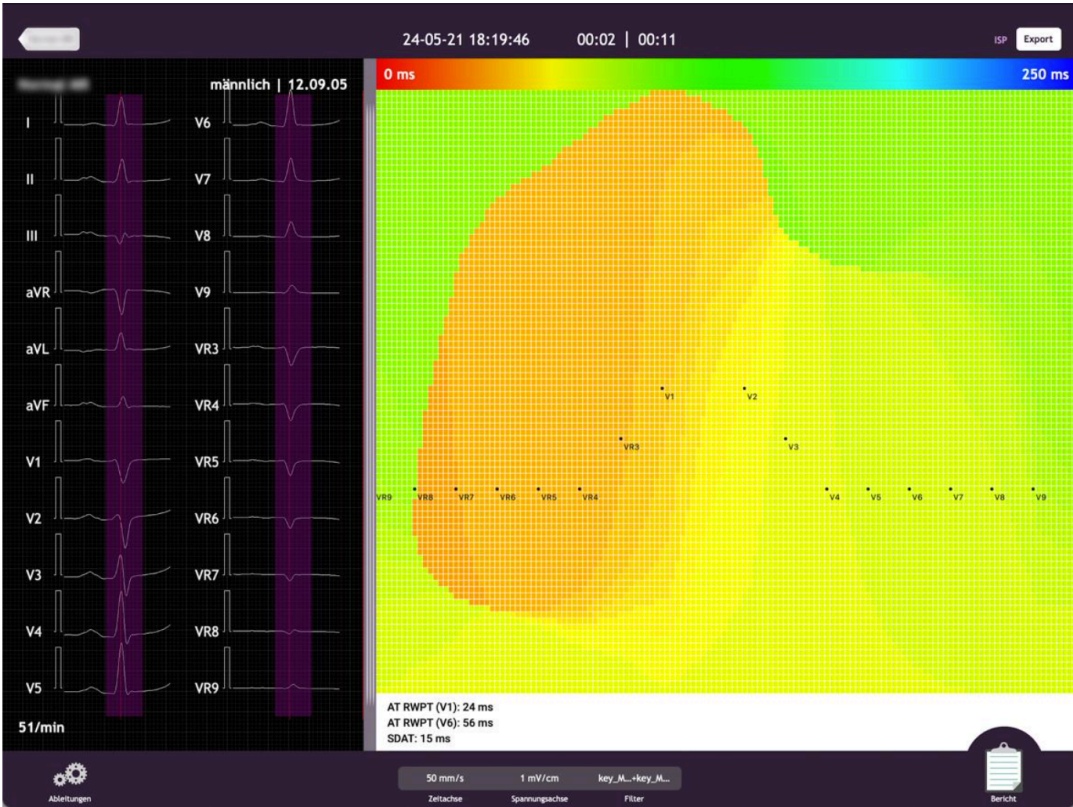
AT RWPT(V1)
AT RWPT(V6)
VEU

R Wave Peak Time V1
R Wave Peak Time V6
Ventricular electrical uncoupling:
 $AT\ RWPT(V1) - AT\ RWPT(V6)$

An example of a healthy heart with normal electrical conduction.

Activation initiates on the right side of the thorax and progresses rapidly and continuously to the left.

The activation times are brief and uniform.



Case of LBBB where activation moves around a line of blockage in a U shape.

