Technical Considerations Prior to CRT Implant: Quadripolar LV Lead, Adaptive CRT and Something Else? 2015 Update

ALAN CHENG, MD
ASSOCIATE PROFESSOR OF MEDICINE
JOHNS HOPKINS UNIVERSITY SCHOOL OF MEDICINE

JANUARY 24, 2015
Disclosures

- Grants: NIH R01 HL 091062, NIH R01 HL103946
- Honorarium: Boston Scientific, St. Jude Medical
- Consultant: Medtronic
The Clinician’s Dilemma: Innovations

PROBLEM

SOLUTION
CRT Non-Response: The Problem

Percentage Non-responders to CRT

- Hard outcome measures
- Remodeling measures
- Soft clinical function measures
- Clinical composite measures

Europace 2012;14:1236
Mortality in CRT Non-Responders Compared to Well-known Malignancies

Cleveland Clinic CRT survival data

5 year survival data for England and Wales

Rickard et al. Heart Rhythm 2014;11:412
CRT: Innovations Toward Improving the Odds

70% → ? → >90%

- Improved Lead Placement
- Improved Patient Selection
- Improved Device Programming
Improved Patient Selection: Improved Understanding

- **LBBB better v. nLBBB**
- **Wider QRS more likely to respond**
- **Women with mild HF do better** (Arshad et al. JACC 2011;57:813)
  - Women respond more to AV optimization (Cheng et al. Heart Rhythm 2012;9:736)

- **Changes in 2012 Guidelines** (Tracy et al. Circulation 2012;126:1784)
  - Patients with LBBB>150msec preferred
  - Do not implant CRT in nLBBB<150msec with NYHA Class I or II symptoms
CRT: Innovations Toward Improving the Odds

70% ? >90%

- Improved Lead Placement
- Improved Patient Selection
- Improved Device Programming

Quadripolar LV Lead
Reasons for CRT Non-Response

Mullens et al. JACC 2009;53:765
Like Real Estate, Location Matters

Helm et al. Circulation 2007;115:953

Sweet spot ~43% of LV free wall

Khan et al. JACC 2012;59:1509

Heart Failure and Death Per Lead Location

Helm et al. Circulation 2007;115:953

Khan et al. JACC 2012;59:1509
Current Problems with CS Lead Implantation

- Wide variability in coronary vein anatomy (van de Veire et al. JACC 2006;48:1832)
- ~55% have just 1 suitable vein target (Khan et al. Europace 2009;11:1491)
- No significant difference between ICM and NICM
- Stability inconsistent within a tributary
- Basal sites preferred but least stable
- Significant dP/dt differences by even 2cm (J Thorac Cardiovasc Surg 2004;127:1641)
- Phrenic nerve stimulation
Phrenic Nerve Stimulation: Non Quad

Prevalence 37% at implant

Strongest risk factor: lead in Posterolateral, midseptum

50%, 24% PNS noted in F/U for unipolar and bipolar

PNS detected only in non-supine position in 38%

Note: If bipolar programmable, no revision or CRT off needed

Flavors of Quad Pacing Leads

Biotronik

4.8 F body

21–20–20 mm electrode spacing

Spiral L

Spiral S

Straight

Fluoro ring

Fluoro ring

5.2 F body

5.3 F body

5.1 F electrodes

4 F electrode

4.7 F body

12 mm

12 mm

12 mm

12 mm

12 mm

12 mm

12 mm

12 mm

12 mm

12 mm

4.0 cm

4.0 cm

7.5 cm

7.5 cm

7.5 cm

7.5 cm

7.5 cm

7.5 cm

20.5 mm

7.5 mm

7.5 mm

7.5 mm

0 cm

5.2 F body

4.7 F body

Quartet

4.0 F tip

20–10–17 mm electrode spacing

St Jude Medical

US FDA

US FDA

CE Mark

CE Mark

CE Mark

Rinaldi et al. Europace 2015;17:7
St Jude Medical Quartet LV Pacing Lead

Quartet™ LV Lead 1458Q

10 VectSelect Quartet™ Vectors

<table>
<thead>
<tr>
<th>Vector</th>
<th>Cathode to Anode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D1 → M2</td>
</tr>
<tr>
<td>2</td>
<td>D1 → P4</td>
</tr>
<tr>
<td>3</td>
<td>D1 → RV Coil</td>
</tr>
<tr>
<td>4</td>
<td>M2 → P4</td>
</tr>
<tr>
<td>5</td>
<td>M2 → RV Coil</td>
</tr>
<tr>
<td>6</td>
<td>M3 → M2</td>
</tr>
<tr>
<td>7</td>
<td>M3 → P4</td>
</tr>
<tr>
<td>8</td>
<td>M3 → RV Coil</td>
</tr>
<tr>
<td>9</td>
<td>P4 → M2</td>
</tr>
<tr>
<td>10</td>
<td>P4 → RV Coil</td>
</tr>
</tbody>
</table>

~60% using nonconventional dipoles
(M. Gold, personal communication)
Medtronic Quadripolar Lead

- Steroid elution on all electrodes
- Short Bipolar Electrode Spacing option to avoid phrenic stimulation

CE Mark 2013
US FDA 2014
Shorter Electrode Spacing

Greatest Δ at closer spacing
97-100% of PNS with quad resolved with reprogramming
Crossley et al. Heart Rhythm 2015; in press

Sensing worse with closer spacing
Biffi et al. Circ AE 2012;5:815-20
Threshold Variance within a Tributary

\[ \Delta 2.2 \text{V} \]

\[ \sim \Delta 2.4\text{-}3.5 \text{yrs!} \]
Hemodynamic Effects of Differing Pacing Site in Quad Lead

- 20 LBBB patients (75% NICM) with quad leads
- Tested all pacing configurations for \( \frac{dP}{dt} \)
- \( \frac{dP}{dt} \) different from pacing sites along same vein in all patients
  - 21.3% increase v. 31.3% increase
- Other study showed intravein difference ~6.5% and intervein difference ~16% (PACE 2012;35:196)

Asbach et al. PLoS ONE 2013;8:e67235
Quadripolar Lead Advantages

- ~40% had PNS: quad lead reduced need for lead repositioning in 72% of patients (PACE 2011;34:484-9)
- LV dyssynchrony “hotspots” are “heterogeneous” (Spragg et al. JACC 2010;56:774)
  - Potential for simultaneous multisite pacing (CE Mark 2013) or wider bipole (Valzania et al. JICE 2013;38:61)
- Potential improvements in hemodynamic response
- SJM reports ~90% of de novo CRT use quads
Quad Lead Disadvantages

- Theoretically higher risk for lead malfunction (more components, more possibilities for failure)

- Compromised handling characteristics
  - More stiff metal
  - Potential for lead movement after implantation

- Larger size leads
  - 5.1F quad, 4.7F bipolar, 4.5F unipolar (BS Acuity Spiral)
CRT: Innovations Toward Improving the Odds

70% \rightarrow ? \rightarrow >90%

- Improved Lead Placement
- Improved Patient Selection
- Improved Device Programming
- Adaptive CRT Pacing
Reasons for CRT Non-Response: Timing

Mullens et al. JACC 2009;53:765
Reasons for Loss of CRT Pacing

Cheng et al. Circ AE 2012;5:884

Suboptimal AV delays
AdaptivCRT: Next Best Thing Since Pop Tarts?

1. LV only pacing is better
2. Optimal AV is dynamic
Intrinsic AV conduction present?

- Any HR?

AdaptivCRT (aCRT) Algorithm

Regular rhythm?
- yes
  - Evaluate intrinsic conduction
  - Intrinsic AV conduction normal and HR≤100 bpm?
    - yes
      - LV only ("fusion") pacing
      - AV: ~70% of intrinsic AV
    - no
      - BiV pacing
      - AV: P-wave* + 30 ms, but at least 50 ms before RVs
      - VV: programmed on the basis of measured QRS duration

As-RVs≤200 ms or Ap-RVs≤250 ms

Courtesy: D. Lustgarten
LV Only Pacing Fusing with Intrinsic RV Activation

RV-Synchronized LV Pacing

Adaptive LV

60 BPM
What Is Adaptive BiV Pacing?

**AV OPTIMIZATION**

The AV delays are updated every minute based on AV interval and P-wave width measurements. (30ms added to P wave width) (but at least 50 ms before the intrinsic QRS)

**V-V OPTIMIZATION**

The ventricular pacing configuration (RV->LV or LV->RV) and V-V pace delay are updated every minute based on AV interval and QRS width measurements.
An Even More Physiological Pacing: Changing the Sequence of Ventricular Activation

E. de Teresa, J. L. Chamorro, L. A. Pulpén, Carmen Ruiz, Isabel R. Bailón, J. Álvarez, M. de Artaza

Summary: Physiological pacing includes preservation of A-V sequential stimulation and adaptation of heart rate to body requirements. However, the sequence of ventricular activation (VA) is also important. In four patients with aortic valve disease, LBBB and HV > 70 msec a Medtronic Ventritex DDD pacemaker was implanted at the time of aortic valve surgery. The ventricular electrode was placed in the free wall of the LV. With different pulse generator A-V intervals (PG-AV), we obtained: a) LBBB morphology when PG-AV = A-V conduction interval (C-AV); b) “RBBB” morphology when PG-AV < C-AV, and c) intermediate (“fusion”) morphology when PG-AV = C-AV. An mean delay of 70 ± 5 msec between the spontaneous activation of RV and arrival of stimulation to ventricular electrode in LV favored these fusion beats. The sequence of mechanical ventricular emptying was non-invasively assessed by radionuclide (Te-99 m Pyo labelled red blood cells) study of the “wave of emptying” and of phase histograms, using the Fourrier’s analysis. The most “normal” pattern was found in C, the ejection fraction (radioisotopic cineangigram) was 0.59 ± 0.035 in C versus 0.51 ± 0.047 in B (p < 0.001) and 0.47 ± 0.045 in A (p < 0.001). We conclude that an appropriate placement of ventricular electrode besides a correct programation of A-V delay in DDD pacemakers allows for a more physiologic ventricular activation in patients with LBBB, improving their ventricular performance.

Introduction

The aim of achieving an artificial heart stimulation as “physiologic” as possible has until now focused in sequential atrioventricular activation and in the modification of heart rate in accordance with the body requirements (1). The use of dual chamber systems (VDD, DVI and DDD modes) offers a reasonable way of solving the problems derived from dissociated atrioventricular activation, an even some new investigational devices may adjust the pulse generator rate to instantaneous variations in QT interval, thus allowing automatic variations of heart rate in response to autonomic nervous tonus, even in absence of normal sinus function (2).

The sequence in which both ventricles are activated seems to have also some importance (3), although this is not easily proved because of the methodological difficulties of analyzing “in vivo” ventricular activation (VA). Recently a computerized analysis of radionuclide cineangigram (RCA), based on the application of Fourier’s Analysis for studying cyclic functions, has been used as a non-invasive method of assessing VA (4). Using this technique we have tried, in selected patients with left bundle branch block (LBBB), to obtain a pattern of VA closer to “normal” and to assess its influence on the “wave of emptying” (WOE) and on left ventricular function. The results of this study are presented here.

K. Steinhoch (ed.), Cardiac Pacing
© Dr. Dietrich Steinhoff Verlag GmbH & Co. KG, Darmstadt 1983
Evolving Understanding of LV Only Pacing: 20 Year Odyssey

- LV only pacing provides similar acute hemodynamic improvement in CI (Nelson et al. Circulation 2000; 102:3053)

- Intrinsic RV activation “better” (Varma et al. JACC Cardiovasc Imaging 2010; 3:567)

- LV only pacing better in some instances (van Gelder et al. JACC 2005; 46:2305)
  - Optimal when HR<100 (Vollmann et al. Circulation 2006;113:953)
  - Optimal when AV delay 60-85% of intrinsic PR (Khaykin et al. Europace 2011;13:1464)
aCRT and Rates of HFH and Death

Post hoc study: Higher Percentage Synchronized LV Pacing in the aCRT Arm had a lower rate of death and HFH

AdaptivCRT™ Arm Only

Time to Heart Failure Hospitalization or All-Cause Death
(With Number at Risk)

Logrank
P = 0.003

45% had >50% LV only pacing

Younger
More LBBB
More NICM
More women

AV Optimization: Others Have Tried

SmartDelay

QuickOpt

SMART AV

FREEDOM
SmartDelay

- 117 pts PATH-CHF
- Linear regression equation derived
- Optimal CRT AV delay based on width of QRS
  - Wider QRS, shorter AV delay (more LV activation from pacing)
  - Narrow QRS, longer AV delay

We tested the hypothesis that the degree of pre-excitation required to provide optimum resynchronization can be predicted from the intrinsic atrioventricular (AV) interval. **Methods:** We tested 117 patients (NYHA class II-IV, EF < 30%) in the PATH CHF studies. 99 tests in 80 patients were used in the development data set (DST) and 50 tests/37 prospective patients constitute the test data set (TST). Intrinsic AV intervals were measured from the atrial event to the earliest peak in the ventricular leads. Linear regression coefficients between the AV delay that provided optimum dP/dt_max and the measured intrinsic AV interval were separately calculated for the cases with QRS > 150 ms & QRS ≤ 150 ms in the DST. Using these coefficients we calculated the estimated optimum AV delay for the cases in the TST and for all cases. The improvement in dP/dt_max at actual optimum AV delay (dP/dt_opt) was compared with the improvement in dP/dt_max obtained at the estimated optimum AV delay (dP/dt_est) both for the patients in the TST and for the entire population. **Results:** For the patients in the TST group dP/dt_est/.99*dP/dt_opt/.1.75 (r^2=0.96, p=0.0001; ±.03 p=0.0001, and ±.043 p=0.0002 respectively). For the entire population, depicted in the Figure, dP/dt_est = 1.01*dP/dt_opt - 2.19 (r^2=0.97, p<0.0001; ±.01 and ±.026 respectively, p<0.0001). **Conclusion:** The AV delay that provides optimum dP/dt_max can be reliably predicted from the intrinsic AV interval.

Aurrichio et al. JACC 2002;39(s1):124
**How does SmartDelay work?**

1. LRL to 40bpm, AV 400msec
   - As → RVS and LVS

2. AP programmed (<100bpm, AV 450msec)
   - Ap → RVS and LVS

3. Calculate AVD (% of PR based on RVs to LVs timing)

4. LV only in Europe if <270msec

**SmartDelay Suggestions:**

1) Paced AV Delay
2) Sensed AV Delay

---

Average HR tested was 74 ± 15 bpm
Average PR was 201 ± 34msec
Smart Delay algorithm won’t work with HR > 100bpm

QuickOpt: AV Interval

9 patients empirically programmed with 30 or 60 ms interval after P wave for optimal AV interval (Meine M et al. J Card Fail 2004;10(S4):S74)

\[ SAV_{opt} = A_S + \Delta \]
\[ \Delta = 30 \text{ or } 60 \text{ ms} \]

SAV is Sensed AV Delay
\( A_S \) is sensed P wave
\( \Delta \) is added interval

\[ PAV_{opt} = A_S + \Delta \]
\[ \Delta = 80 \text{ or } 110 \]

PAV is Paced AV Delay
\( A_S \) is sensed P wave
\( \Delta \) is added interval
QuickOpt: VV Interval

11 pts RHYTHM II and 61 pts RHYTHM VV used to derive optimal VV interval
(Min X et al. PACE 2007;30:S19)

\[ VV_{opt} = 0.5 \times (\Delta + \varepsilon) \]

\[ \varepsilon = IVCD_{LR} - IVCD_{RL} \]
AdaptivCRT: How Unique Is This?

Key Features

Normal AV Conduction
- SMART AV
- Adaptive LV pacing

Prolonged AV Conduction
- QUICKOPT
- Adaptive BiV pacing

ASSESSES INTRINSIC CONDUCTION

Every Minute.

Every Patient Optimized.

Key Features

HR<100bpm
%PR to provide fusion

Opt AV via adding 30ms
Opt VV based on V-V timing

Clinical benefit to be determined...
What Is Really Unique About the Adaptive CRT Algorithm?

- Dynamic Optimization
  - Only Medtronic systems
- Adaptive LV only pacing?
  - Aims for fusion like Smart Delay
  - Can modify with long V-V offset
- Adaptive Biventricular pacing?
  - AV optimization similar to QuickOpt
  - VV optimization similar to QuickOpt
Something Else?: SonR Optimization

- CRT optimization using RV hemodynamic sensors
  - Peak endocardial acceleration ≈ LV dP/dt
- Pilot study showed SonR better (p=0.03)
- Device optimized AVD weekly and VV at clinic
- Composite HFH, NYHA, QOL and death

Ritter et al. Europace 2012;14:1324
Something Else?: Endocardial and Multisite Pacing

- **Multisite Pacing** *(Rinaldi et al. Europace 2015;17:7)*
  - Two broad patterns of LV activation (type I: septum to lateral wall; type II: U shaped activation)
  - Pacing from 2 distinct spots (2 RV & 1 LV OR 1 RV & 2 LV) *(Eur Heart J 2007;28:2610)*

  - Endocardial activation more physiologic, more sites to pace, better thresholds, no PNS
  - Technically challenging and needs anticoagulation
  - Doubling of dP/dt *(Derval et al. JACC 2010;55:566)*