Atrioventricular coupling and ventricular interval regularity during atrial fibrillation: A frequency-dependent phenomenon

Masè M¹, Marini M², Disertori M and Ravelli F¹

¹ Department of Physics, University of Trento, Italy
² Division of Cardiology, S. Chiara Hospital, Trento Italy
AV node
specialized conduction system of the heart, which connects the atria and ventricles

**Functions**

- time delay to optimize the coupling between ventricular filling and contraction
- filtering of high-rate atrial inputs, safeguard against life-threatening ventricular arrhythmias
Nonlinear dynamics provide a unified framework to describe block processes in AV conduction.

**J. Honerkamp**
Fakultät für Physik, Universität Freiburg, Hermann-Herder-Str. 3, D-7800 Freiburg i. Brsg., Federal Republic of Germany

**Prediction of complex atrioventricular conduction rhythms in humans with use of the atrioventricular nodal recovery curve**

**Alvin Shiner, Ph.D., Howard Dubansky, B.Sc., Michael Rosengarten, M.D., Michael R. Guevara, Ph.D., Stanley Nattel, M.D., and Leon Glass, Ph.D.**
*Circulation* 76, No. 6, 1196–1205, 1987.

**ATRIAL STIMULATION** at increasing atrial rate

**AV block processes resembling phase-locking transitions in dynamical systems**

1:1 | 6:5 | 4:3 | 2:1
ATRIAL FLUTTER

Phase-locking transitions can be observed during regular, high-rate spontaneous arrhythmic condition.

What happens during AF?
Atrial Fibrillation

- Irregular high-rate atrial impulses (400-600 bpm) due to the «chaotic» propagation of multiple wavelets
- Lost of 1:1 AV conduction
- Irregular ventricular activation, usually with incessant tachycardia

AIMS

1. To investigate the dynamics of AV coupling during AF
2. To assess the influence on the variability and regularity of ventricular interval
METHODS
METHODS: Experimental Setting

To study the AV node in a dynamical sense

Different atrial input rate should be tested

TO USE

Spontaneous atrial rate changes in the first minutes of an AF episode

Ravelli F et al., JCE, 18, 60-65, 2007
Patient Population

10 patients with paroxysmal atrial fibrillation (age 54 ± 22 yrs, 1 female)

Electrophysiological study

Induction of AF by burst atrial pacing
- 5 s bursts, 4mA output, 2 ms pulse width
- from 400 ms cycle length to atrial refractoriness (step 20 ms)

Recordings of few minute length
- Atrial activity by a quadrupolar catheter in the right atrium
- Ventricular activity by surface ECG
METHODS: Construction of the AV synchrogram

AV synchrogram -> identifies instances of $n:m$ atrioventricular coupling by a stroboscopic observation of the ventricular phase at times triggered by atrial activation

Extract $A_k$ atrial and $V_j$ ventricular activation times

$$\phi_v(t) = 2\pi \frac{t - V_j}{V_{j+1} - V_j} + 2\pi j \quad V_j \leq t < V_{j+1}$$

$$\psi_m(A_k) = \frac{1}{2\pi} \left[ \phi_v(A_k \mod 2\pi m) \right]$$

$\exists k \geq 1 \quad |\Psi_m(A_{i+n}) - \Psi_m(A_i)| < \varepsilon$

$i \in \{l, \ldots, l + kn - 1 \mid 0 < l < N - kn + 1\}$

Pattern assessment by testing with shuffled surrogate phase series

METHODS: Characterization of the AV synchrogram

Average parameters

- percentage of coupled beats
  \[ p_c = \frac{\sum_{j=1}^{M} (A_{ej} - A_{1j})}{T} \cdot 100\% \]

- maximal duration of coupled epochs
  \[ l_{\text{max}} = \max_j (A_{ej} - A_{1j}) \]

- average nodal conduction ratio
  \[ CR_m = \frac{\sum_{j=1}^{M} (m_j / n_j) \cdot (A_{ej} - A_{1j})}{\sum_{j=1}^{M} (A_{ej} - A_{1j})} \]

AV response curve

To outline frequency-dependences, CR displayed as a function of AA

METHODS: Quantification of Ventricular Variability/Regularity

VARIABILITY in Time-domain
- \( SD_{RR} \)
- \( RMSSD_{RR} \)
- \( pRR \) 10-90

IRREGULARITY in Entropy-domain

\[ SampEn(m, r) = -\log \frac{A}{B} \]

where

\[ A = n. \text{ of template vector pairs of length } m+1 \text{ having } d[X_{m+1}(i), X_{m+1}(j)] < r \]

\[ B = n. \text{ of template vector pairs of length } m \text{ having } d[X_m(i), X_m(j)] < r \]

\( m = 1, 2; \ r = 0.15, 0.2, 0.25*SD; \ N = 100 \text{ and } 150 \)

Corino VD et al., JCE, 26(2):137-41, 2015

RESULTS
RESULTS: AV coupling 1

Progressive decrease in $CR$ at decreasing $AA$

Existence of significant synchronized epochs ($p_c=26.3\%, l_{max}=4.2$ s)

$m_{AA} = 137.0 \pm 19$ ms  
$CR_m = 0.27$

$m_{AA} = 124 \pm 16$ ms  
$CR_m = 0.23$
1. Decrease in CR at the shortening of atrial intervals
2. Higher order patterns less common than n:1 patterns
3. Farey sequence ordering of n:m patterns as a function of atrial rate (n+N:m+M orders between n:m and N:M)

These features are consistent with the nonlinear recovery properties of the AV node
Atrial rate increase determines a decrease in the occurrence, stability and locking ratios of AV coupling patterns.
RESULTS: Ventricular Response

VENTRICULAR RATE = VENTRICULAR VARIABILITY

VENTRICULAR IRREGULARITY

$m=2$, $r=0.2$ (significant differences also for 0.15 and 0.25)

Advanced levels of AV block at higher atrial rates determine an increase in the variability and irregularity of ventricular intervals
CONCLUSIONS

- Instances of AV coupling exist during AF, whose dynamics can be described by AV synchromogram analysis.

- AV coupling during AF is a frequency-dependent phenomenon:
  - AV coupling occurrence and stability decrease at increasing atrial rate
  - AV locking ratios are ordered according to a Farey sequence as a function of atrial rate.

- Instability of AV coupling and advanced levels of blocks at higher atrial rates determine higher variability/irregularity of ventricular intervals.

- Acute changes occurring during AF may determine adverse hemodynamical effects, increasing acute risks in AF patients.

- These factors should be taken into account in the development of rate control strategies for AF.
THANKS for your attention

QUESTIONS?

Funding
Fondazione Cassa di Risparmio di Trento e Rovereto