Mechanical Modulation of Heart Rate and Rhythm

The Cardiac Mechano-Electric Feedback Lab

Contact: peter.kohl@dpag.ox.ac.uk

Plan

• Introduction to the mechano-sensitive heart
• Definition of Mechano-Electric Feedback (MEF)
• Physiological effects of MEF (heart rate modulation)
• Pathological effects of MEF (arrhythmogenic)
• Therapeutic potential of MEF (anti-arrhythmic)
• Summary

Cardiac Mechano-Electric Feedback

• Intra-cardiac, non-neural mechanisms
• that affect heart rate or rhythm
• in direct electrophysiological response
• to changes in the cardiac mechanical environment.

Effects of MEF on Heart Rate & Rhythm

PHYSIOLOGY
• Venous return increases heart rate
  (Bainbridge 1915, Deck 1964, Donald & Shepherd 1978)
• Respiratory sinus-arrhythmia
  (Ludwig 1847, Bernadi 1989, Horner 1996)

PATHOLOGY
• Arrhythmia after transient mechanical stimulation (incl. CC)
  (Nélaton 1876, Meola 1879, Schlomka 1932, Maron 1995)
• Arrhythmia in chronically dilated heart (atria & ventricles)
  (Weaver 1976, Janse 1992, Taggart 1999)

THERAPY
• Mechanical resuscitation: pre-cardial percussion, thumping
  (Schott 1920, Hyman 1930, Befeler 1978)
**Chronotropy**

"Acceleration of heart rate [...] caused by impulses arising within the heart."

FA Bainbridge. The influence of venous filling upon the rate of the heart. J Physiol, 1915/50:65-84.

**Isolated SAN**


**Venous Return → HR (In Man)**

<table>
<thead>
<tr>
<th>Mean Arterial Pressure [mmHg]</th>
<th>90</th>
<th>90</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse Pressure [mmHg]</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Central Venous Pressure [mmHg]</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Heart Rate [beats/min]</td>
<td>68</td>
<td>84</td>
<td>68</td>
</tr>
</tbody>
</table>


**Respiratory Sinus Arrhythmia**


**Internal Mechanical Stimulation**


**MEF & Heart Rhythm I**

*Patho-Physiological Effects*
Sudden Cardiac Death by Commotio cordis

Early Fundamental Insight: 70 yrs ago

Georg Schломka:
800 experiments on anaesthetised rabbits, cats & dogs
• Non-neural response
• Type of stimulus: brief impact to small area
• Location of stimulus: mid- to lower sternum
• Force of stimulus: medium to large, sub-contusional

Contemporary Insight into SCD by CC

Commotio cordis: Risk Factors

• Type of Stimulus (1930s): brief impact to small area
• Location of Stimulus (1930s): mid- to lower sternum
• Force of Stimulus (1930s): medium to large, sub-contusional
• Timing of Stimulus (1980/90s): early T-wave
Proposed Mechanisms

19th century  Profound Vagal Reflex
1932:  Intra-cardiac Mechanism
20th century  Vascular Crisis
1982:  fast, ECG-dependent effects
21st century  Mechano-Electric Feedback

Definition

Commotio cordis: mechanical stimulation of the heart by non-penetrating (impulse-like) impact to the pre-cordium that, via intrinsic cardiac mechanisms, gives rise to rhythm disturbances of varying type, duration and severity (including sudden cardiac death) in the absence of any such structural damage that would explain the observed electro-physiological effect.

Sustained Stretch

Steady state:  1 sec

Waxman et al., Circulation, 1980/82 843-851.

MEF & Heart Rhythm II

Resuscitatory Potential

‘Fist Aid’ in VT & Early VF

VT  NSR

Pennington et al., NEJM 1970/283 1192-1195.

ILCOR 2000 and 2005 Guidelines

PT for Witnessed Cardiac Arrest:
- asystole pacing
- tachyarrhythmia termination

<table>
<thead>
<tr>
<th>PT: Clinical Utility (Prospective Data)</th>
</tr>
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<tbody>
<tr>
<td><strong>PT for out-of-hospital cardiac arrest:</strong></td>
</tr>
<tr>
<td>Total OOH-CA PT#</td>
</tr>
<tr>
<td>PT effect (any)</td>
</tr>
<tr>
<td>Witnessed CA</td>
</tr>
<tr>
<td>PT induced ROSC</td>
</tr>
<tr>
<td>Discharged alive</td>
</tr>
<tr>
<td>PT-rescued</td>
</tr>
<tr>
<td>Negative side-effects</td>
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</tbody>
</table>

Note: 112 victims showed no ROSC with 'best therapy' either.

Prognostic value? (67% of PT-induced ROSC patients survived, vs. 21% among CPR-induced ROSC).

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**Device-Assisted Mechanical Stimulation**

No timing-dependent side effects (incl. T-wave impact)

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**PT in Asystole: Experimental Validation**

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**‘Fist Aid’ in VT & VF**

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**Determinants of Duality**

- Commotio Cordis
- Pre-cordial Thump

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**Pre-Cordial Impact Safety Considerations**

Mechanical induction of dysrhythmia in adult:
1) Energy levels have to be permissive (> 50 J)?
   then
2) Timing becomes decisive.

**Exception(s):** Severe pre-existing hypoxia?
Summary

Mechanical Effects on Rate & Rhythm

- HR is affected by cardiac mechanical environment
- Transient stretch may trigger PVB / VT / VF
- Sustained stretch promotes arrhythmias
- Pre-cordial thumps have resuscitative potential (little systematic data)