



Circulation Physiology

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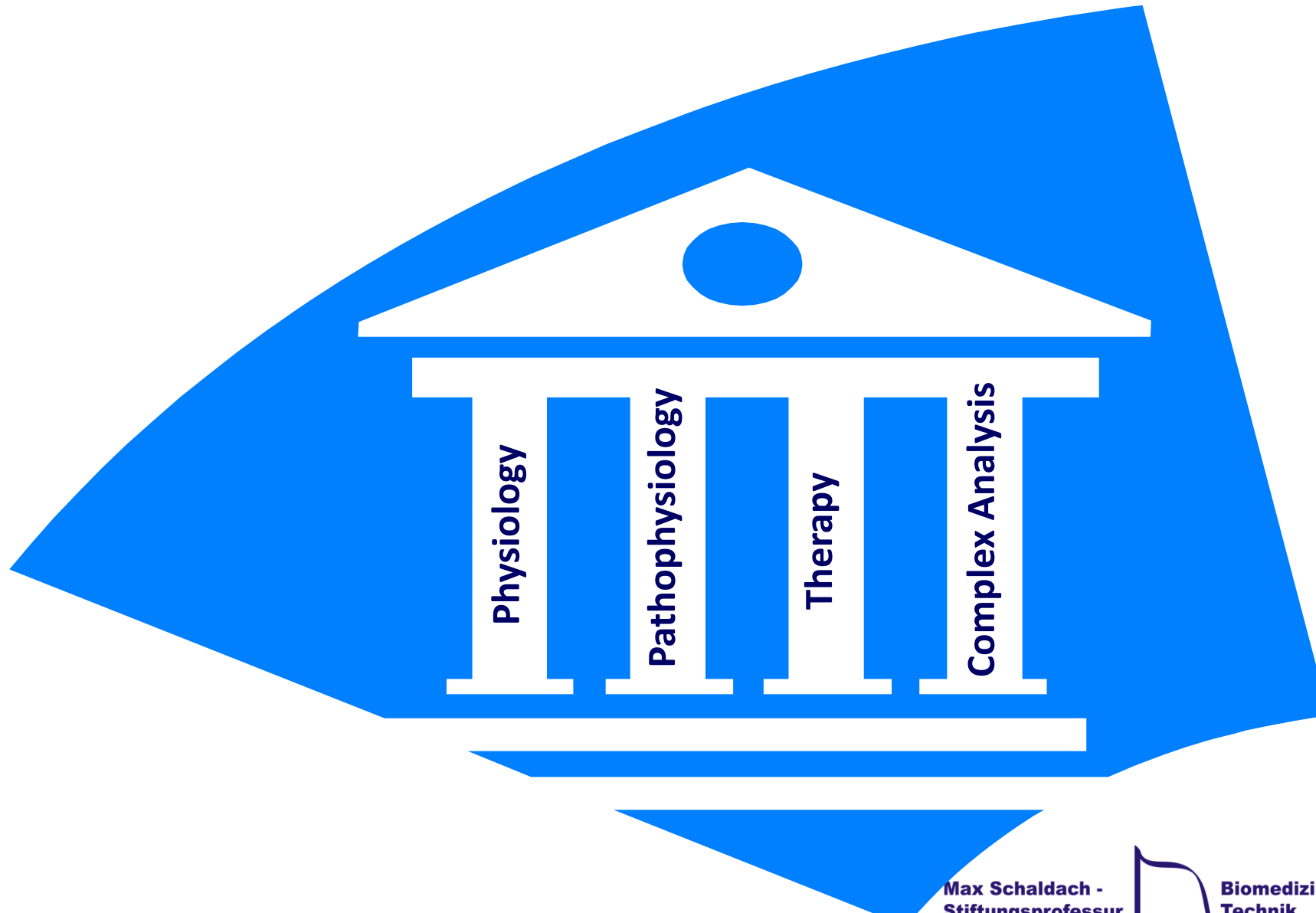
21 - 25 Mar 2010

**Max Schaldach -
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**Biomedizinische
Technik** **MSBT**



Overall Idea



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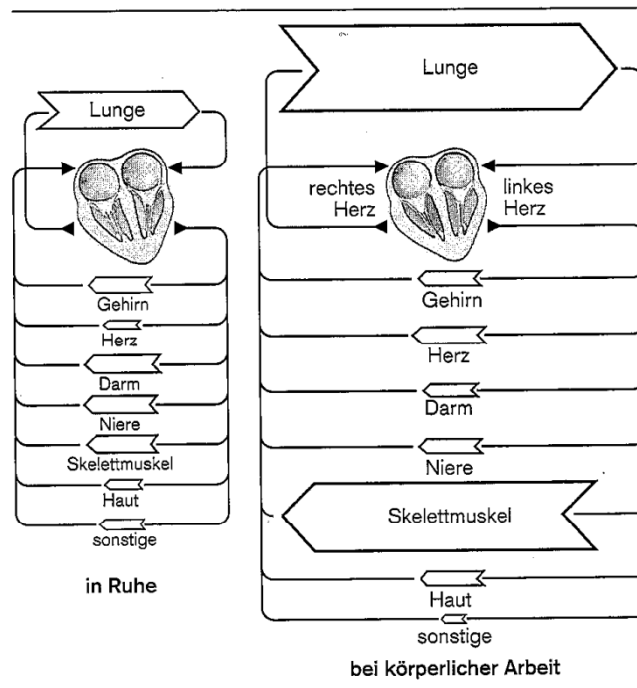
Agenda: Circulation Physiology

- **Circulation Physiology**
- **Heart Physiology**
- **Pathophysiology**
- **Therapy**

Agenda: Circulation Physiology

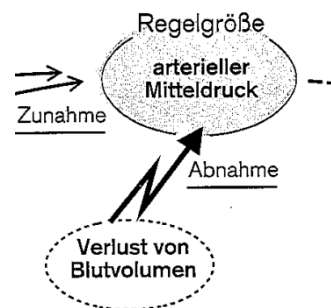
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Circulation Physiology: Overview



- **Tasks and components:**

- Supply and disposal
- Pumping organ: the heart
- Systemic circulation (body)
- Pulmonary circulation (lung)
- Coupled to breathing
- Central vessels
- Peripheric vessels

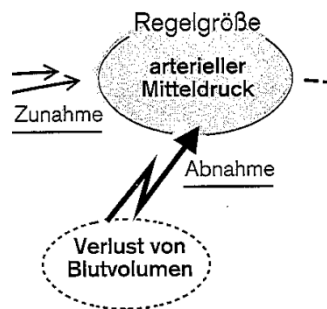
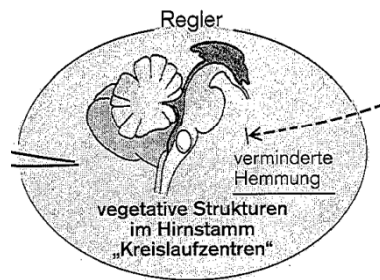
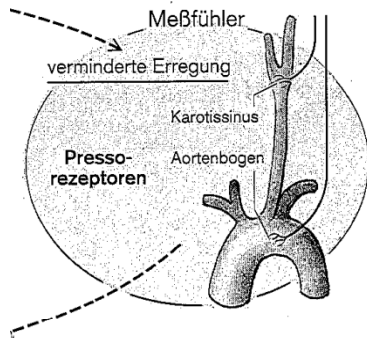


Klinke/Silbernagel (1994)

- **Regulation cycle (Homeodynamic):**

- Sensors for detection of information
- Neural means of processing (ZNS, ANS)
- Different actuators and relevant variables

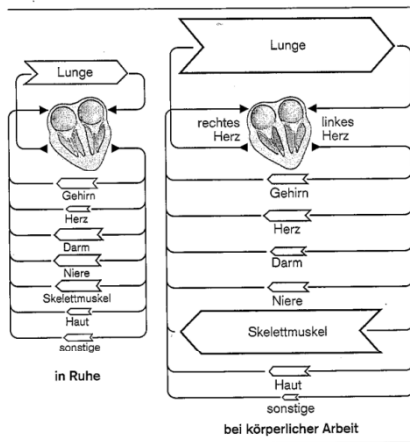
Circulation Physiology: Sensors



Klinke/Silbernagel (1994)

- **Baroreceptor Reflex:**
 - sinus carotis, arcus aortae
 - PD regulation properties
 - Disorders: neuropathy, sclerosis
- **Chemoreceptors:**
 - Partial pressures, pH value
 - Coupling heart rate and breath
- **Local Regulation:**
 - Afferent heart nerves, thoracic pressure
 - Frank-Starling law
 - Cellular receptors (peripheral, heart)

Circulation Physiology: Efferent Nerves and Actuators



Klinke/Silbernagel (1994)

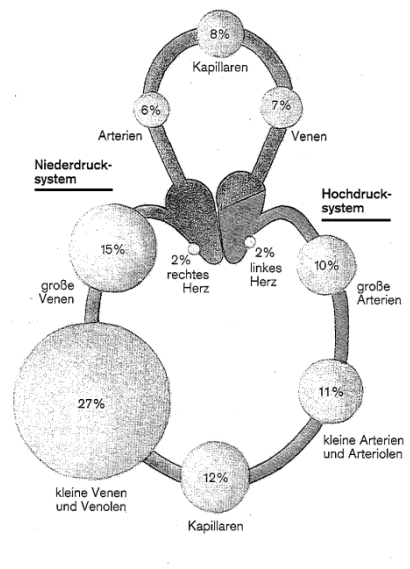


Heart Rate



Contractility

Antagonistic interaction of n. vagus and n. sympathicus



Vascular Resistance



Catecholamines etc.

Circulation Physiology: Standard Values (Hausbeck 2006)

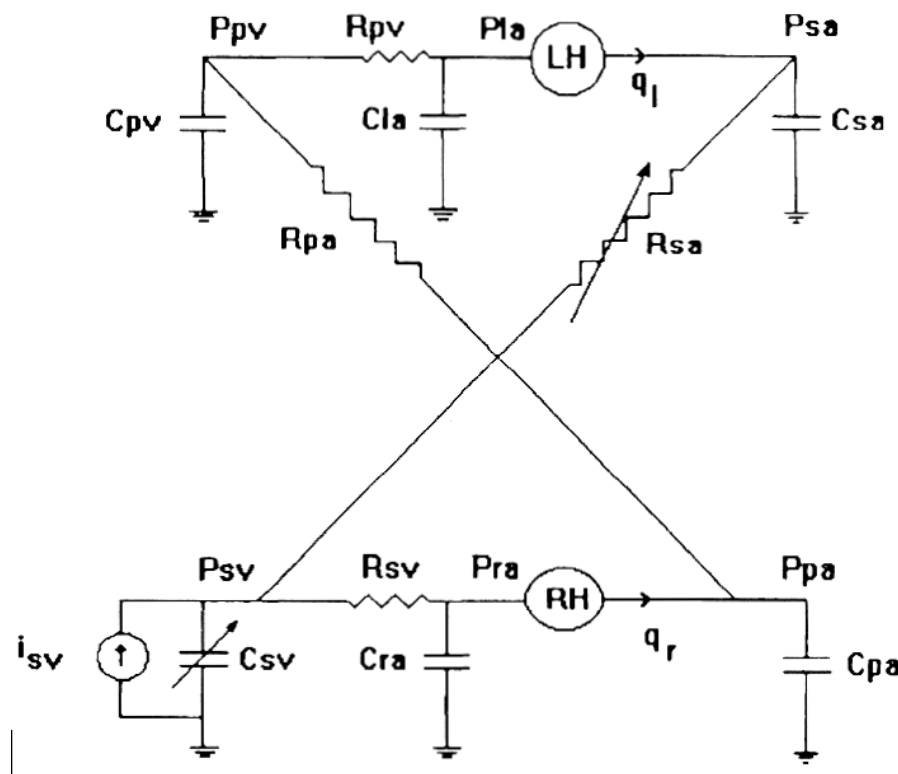
Normalwerte	
Herzrate in Ruhe ¹	50–100 l/min
Herzrate eines Neugeborenen	140 l/min
Herzrate eines 10-jährigen Kindes	90 l/min
Herzrate eines Erwachsenen	60–70 l/min
Schlagvolumen in Ruhe	70 ml
Schlagvolumen unter Belastung	bis 130 ml
Herzminutenvolumen in Ruhe ²	4,9 l/min
Herzminutenvolumen unter Belastung	bis 25 l/min
<hr/>	
Druck im Gefäß	Mittelwert
Aorta	105 mmHg
Kapillaren (arteriennah)	32–37 mmHg
Kapillaren (venennah)	16–21 mmHg
Venen	bis 10 mmHg
reiner Fülldruck aller Gefäße bei Herzstillstand	6–7 mmHg
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Druck bei Herzaktion	systolisch diastolisch
linker Ventrikel	90–130 mmHg 2–8 mmHg
rechter Ventrikel	20–30 mmHg 0–4 mmHg
linkes Atrium	8–15 mmHg 5–9 mmHg
rechtes Atrium	1–5 mmHg 0–2 mmHg
Aorta	90–130 mmHg 60–90 mmHg
Arteria pulmonaris	20–30 mmHg 8–12 mmHg
<hr/>	
Volumen	systolisch diastolisch
Ventrikel in Ruhe	140 ml 60–70 ml
Ventrikel unter Belastung	200–300 ml 10–30 ml
Atrium in Ruhe	11 ml 5 ml

Alter	17–25	26–35	36–45	46–55	>55
<i>HR_r</i> (bpm)					
m:	68,9 ± 10,5	68,9 ± 9,1	72,8 ± 13,0	69,1 ± 7,8	69,8 ± 9,6
w:	76,7 ± 13,5	71,3 ± 12,7	76,5 ± 1,11	71,8 ± 8,8	68,0 ± 9,2
<i>CV_r</i> (%)					
m:	6,03 ± 2,87	5,75 ± 2,17	4,90 ± 1,37	3,89 ± 1,37	3,02 ± 1,29
w:	5,89 ± 2,22	5,24 ± 2,37	3,89 ± 1,37	3,39 ± 1,28	3,39 ± 1,70
<i>RMSSD_r</i> (ms)					
m:	44,7 ± 36,0	38,0 ± 20,1	28,2 ± 21,1	20,4 ± 10,3	17,8 ± 8,9
w:	38,0 ± 30,6	34,7 ± 25,9	22,4 ± 12,4	19,1 ± 10,1	21,4 ± 14,2
<i>totalpower</i> (ms ²)					
m:	4169 ± 3735	3631 ± 3366	2455 ± 1427	1585 ± 1184	1047 ± 665
w:	4266 ± 2255	3020 ± 2706	1950 ± 1808	1380 ± 1324	1175 ± 1053
<i>LF</i> (ms ²)					
m:	1380 ± 1413	1413 ± 1589	977 ± 877	589 ± 528	309 ± 348
w:	1288 ± 1076	1023 ± 1082	617 ± 715	398 ± 633	347 ± 440
<i>HF</i> (ms ²)					
m:	1023 ± 1456	759 ± 802	501 ± 360	200 ± 149	178 ± 138
w:	1097 ± 1122	741 ± 968	389 ± 349	224 ± 268	219 ± 246
<hr/>					
Alter	17–25	26–35	36–45	46–55	>55
<i>CV_d</i> (%)					
m:	10,00 ± 4,02	10,47 ± 3,43	7,94 ± 3,59	6,17 ± 3,26	3,72 ± 1,58
w:	9,77 ± 3,21	9,55 ± 4,31	7,24 ± 2,55	6,17 ± 2,63	4,57 ± 1,95
<i>RMSSD_d</i> (ms)					
m:	57,5 ± 33,4	58,9 ± 31,1	35,5 ± 20,6	33,1 ± 15,8	18,6 ± 10,3
w:	44,7 ± 27,2	50,1 ± 36,0	35,5 ± 16,9	31,6 ± 14,1	22,9 ± 13,9
<i>E – I – Differenz</i> (ms)					
m:	331 ± 116	324 ± 106	263 ± 105	214 ± 113	123 ± 62
w:	363 ± 154	282 ± 156	263 ± 87	204 ± 92	155 ± 86
<i>E/I – Ratio</i>					
m:	1,148 ± 0,01	1,148 ± 0,01	1,138 ± 0,02	1,129 ± 0,01	1,117 ± 0,01
w:	1,151 ± 0,02	1,148 ± 0,02	1,138 ± 0,01	1,132 ± 0,02	1,123 ± 0,01
<i>30 : 15 – Ratio</i>					
m:	1,120 ± 0,02	1,132 ± 0,02	1,126 ± 0,01	1,120 ± 0,01	1,122 ± 0,01
w:	1,135 ± 0,02	1,189 ± 0,02	1,126 ± 0,01	1,117 ± 0,01	1,148 ± 0,02

Analysis: Mean Heartrate and Spontaneous Fluctuations

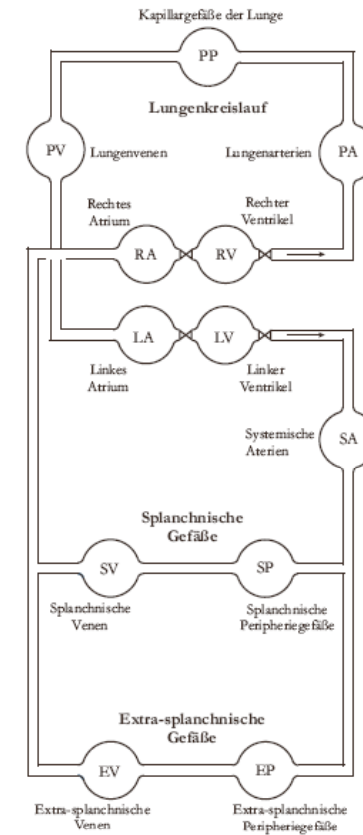
Modelling of Circulation

Equivalent Circuit



Ursino (1998)

Windkessel Model



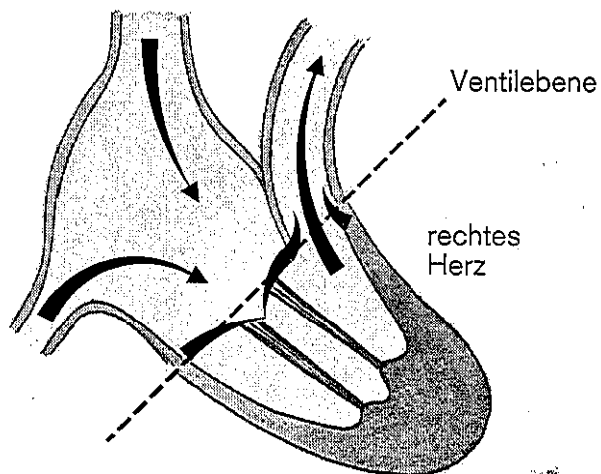
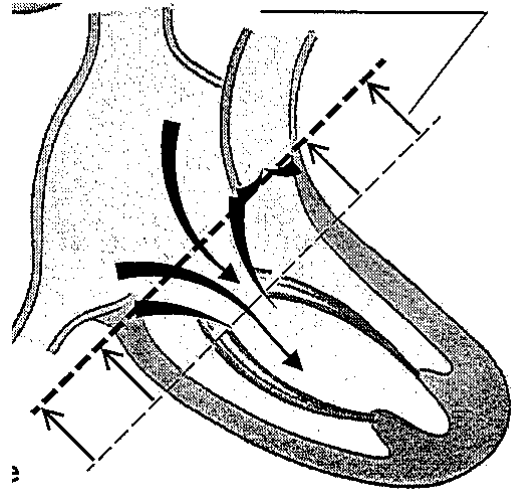
Ursino (1995)

Description and analysis by **nonlinear coupled** differential equations

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Heart Physiology: Basics of Anatomy

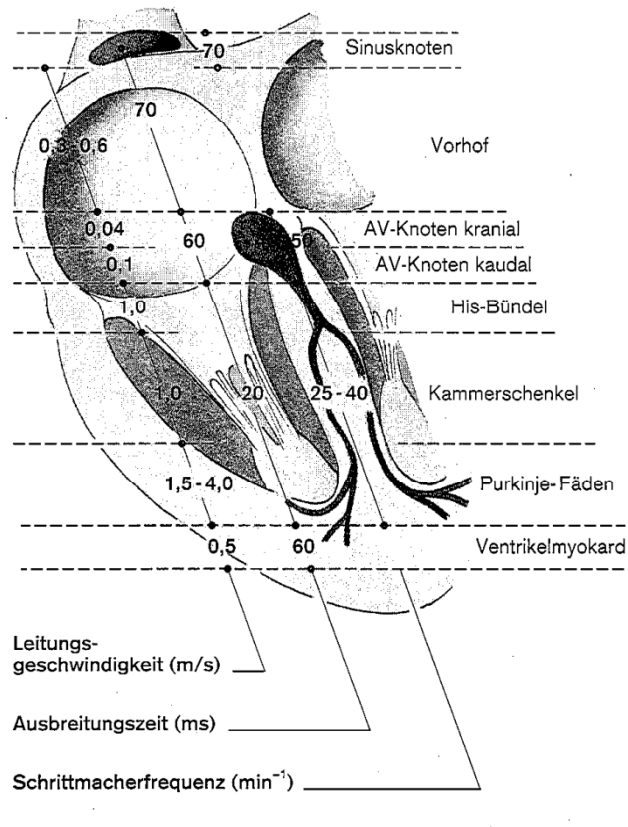


Klinke/Silbernagel (1994)

- **Diastole (Relaxation):**
 - Atrial filling
 - Sinus node: origin of excitation
 - Beginning of atrial contraction
 - Opening of AV valves
- **Systole (Contraction)**
 - Ventricular filling continues
 - Closure of AV valves
 - Opening of aortic valve
 - Ejection of blood volume
- **Disorders:**
 - Improper valve function
 - Lack of contractile force
 - Missing chamber coordination
 - Excitation disturbances

Heart Physiology: Origin and Spread of Excitation

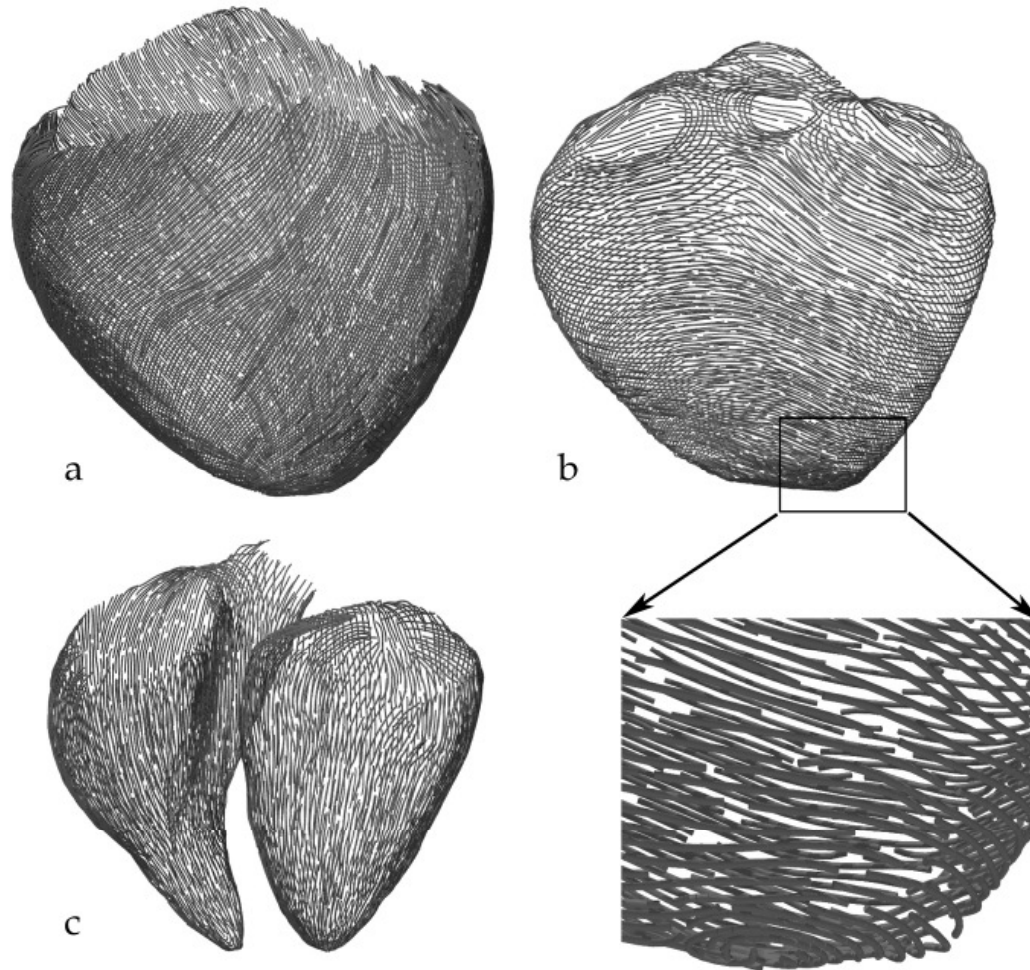
Physiological Sequence of Excitation



Klinke/Silbernagel (1994)

- **Sinus Node:**
 - Proper origin of excitation
- **AV Node:**
 - Delayed spread to chambers
- **Tawara branches und Purkinje fibers:**
 - Homogeneous spread in myocardium
- **Relevant Disorders:**
 - Pulmonary vene activity
 - Reentry tachycardia (valve level)
 - Atrial and ventricular fibrillation
 - Ectopic foci, premature excitation
 - Block of excitation spread

Model of the Heart: Mechanical aspects of Contraction



- **Objective:**

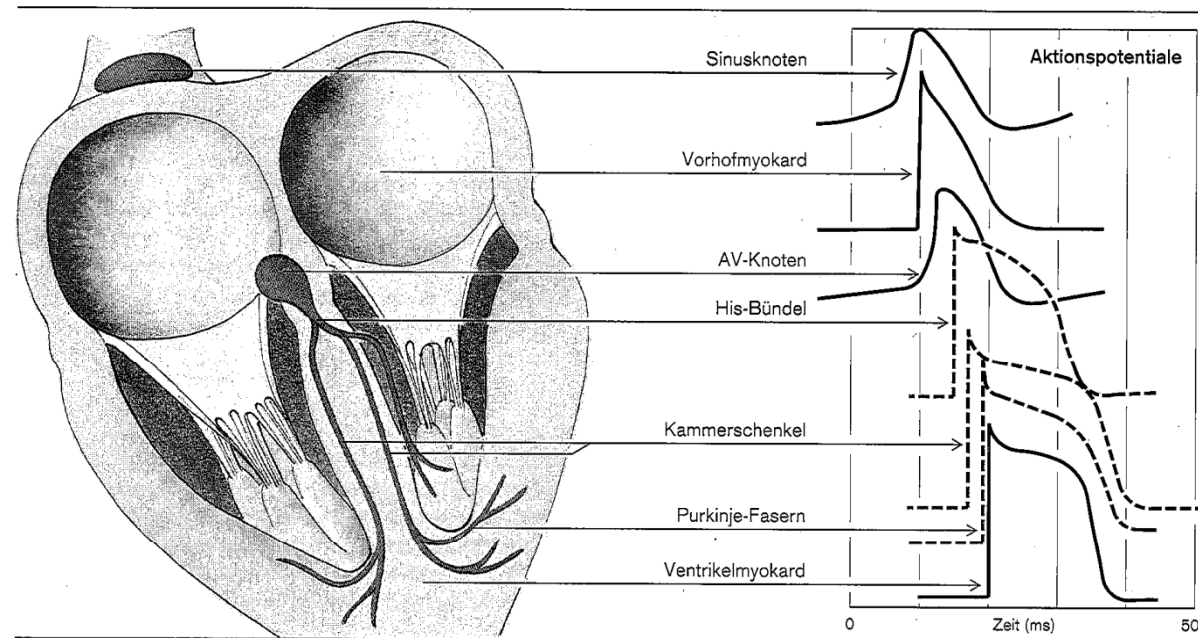
- Model geometric conditions
- Modelling of electrical phenomena

- **Remarks:**

- Finite elements
- Design of anatomical fiber structure
- Complex dynamics of contraction

Lippert (2010)

Heart Physiology: Cellular Level

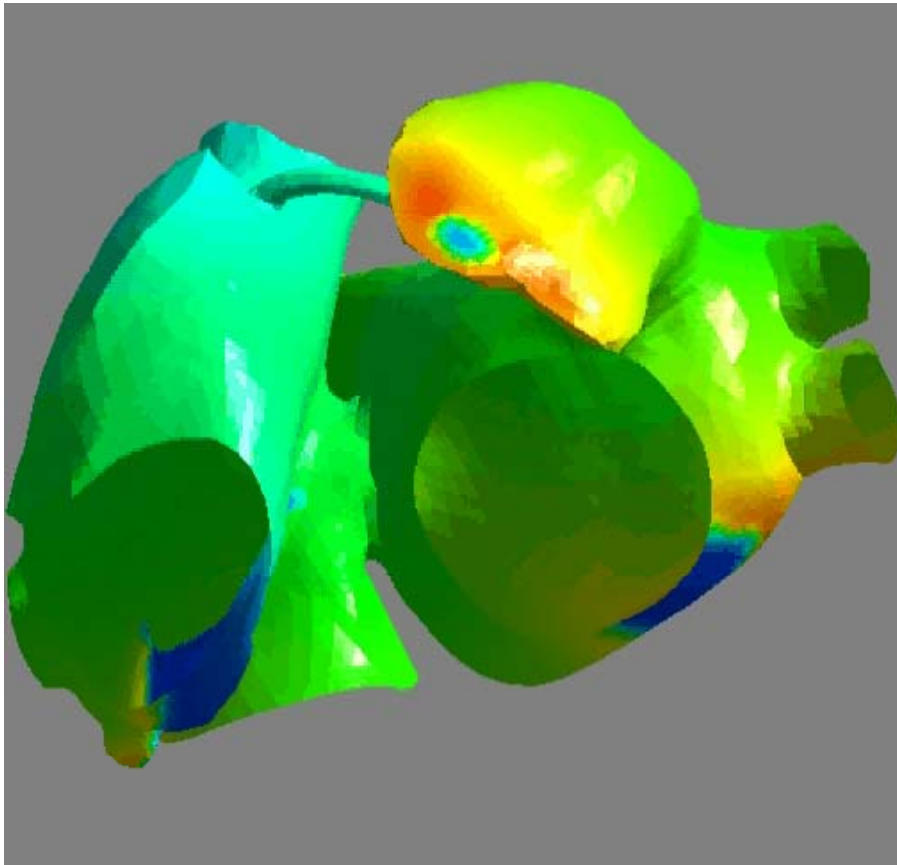


Klinke/Silbernagel (1994)

- **Action Potential** of cardiac cells:
 - Depends on functionality
 - Determines contractility (calcium)
 - Action (and rest) potential determined by ion channels
 - Parameters: voltage, refractory period, coupling

Modelling the Heart: Cell and Tissue Models

Pathological Excitation Spread



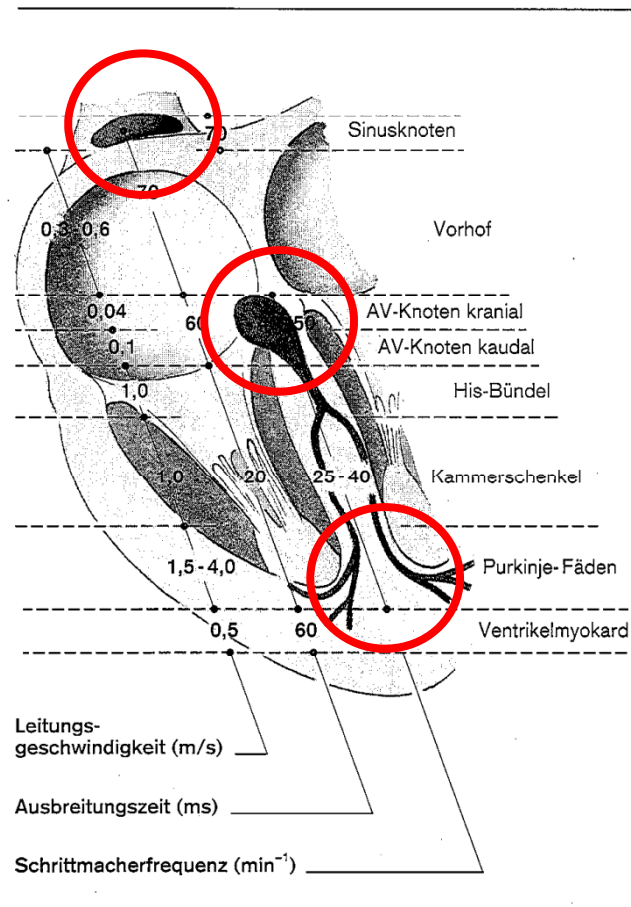
Krätschmer (2002)

- **Objective:**
 - Modelling of rhythm disturbances
 - Identification of possible therapeutic approaches
- **Models:**
 - Cell specific
 - Hodgkin-Huxley (ion ch.)
 - Nygren (atrium)
 - Luo-Rudy (ventricle)
 - Anatomic modelling necessary

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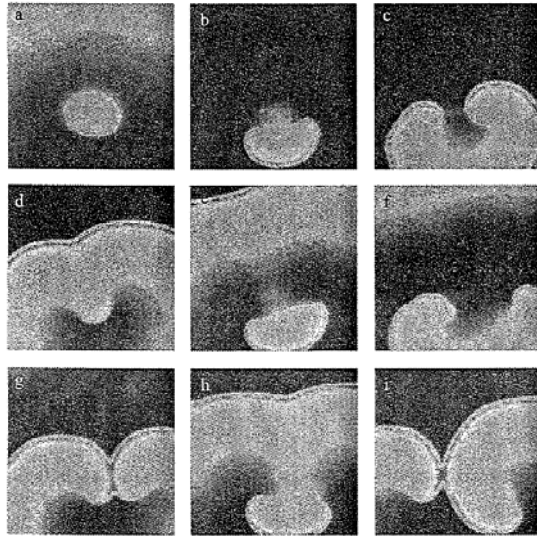
Bradycardia: Disturbances of Excitation Generation and Spread



Klinke/Silbernagel (1994)

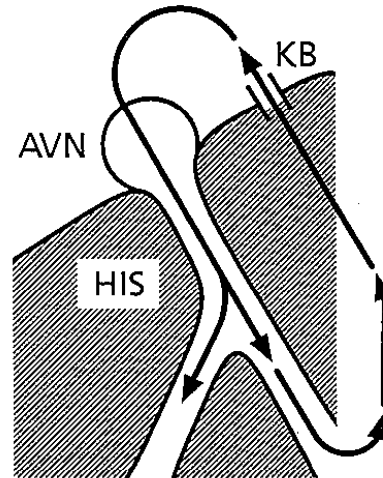
- Disturbance of **sinus node**:
 - Slow substitute rhythm
 - Irregularities
- **AV block** of different grade:
 - Dissociation atrium/ventricle
 - Tachyarrhythmia
- **Bundle Branch** block:
 - Dissociation of ventricles
 - May result in heart failure

Tachyarrhythmia in Atria and Ventricles



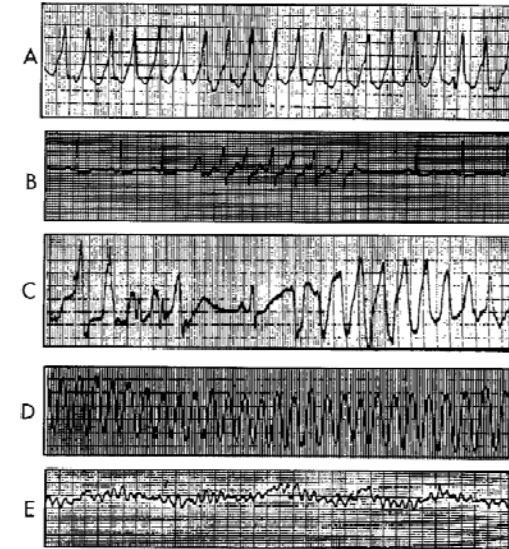
Krätschmer (2002)

Atrial Fibrillation



Kalusche (1996)

AV Reentry

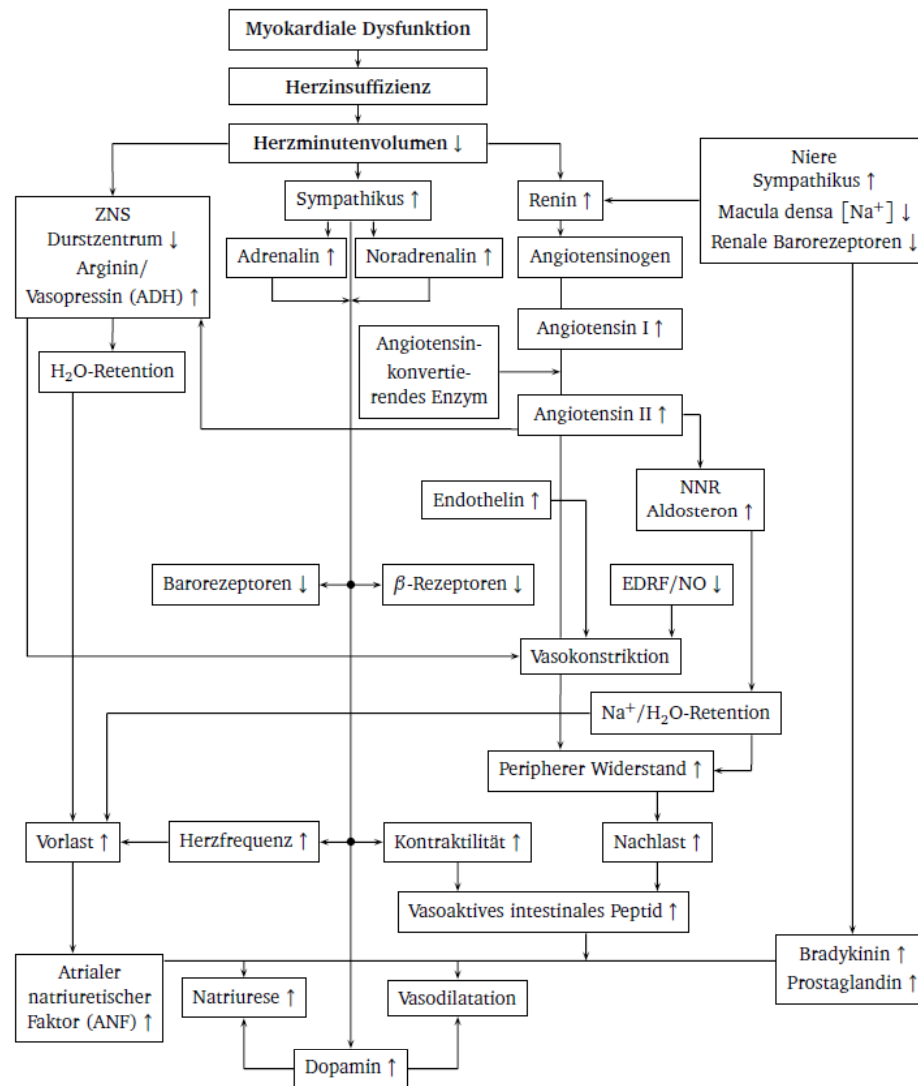


Miller (1991)

Sudden Cardiac Death

- **Factors:**
 - Arrhythmogenic heart muscle (cellular disturbances)
 - Anatomical abnormalities (block, pathways)
 - Triggers: premature beats

Heart Failure: A Vicious Circle



Hauf (1996)

Characteristics:

- Progressive pump failure
- Multiple factors, complex regulatory mechanisms
- Can be “compensated” for a while
- Death by “decompensation”

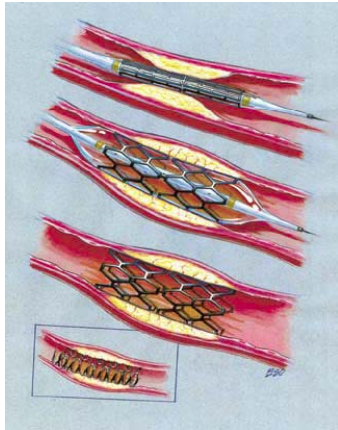
Consequences:

- High morbidity and mortality
- Results in extremely high costs for health system
- Demand for regular monitoring

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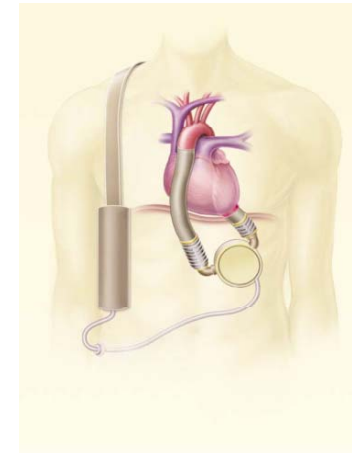
Surgical Therapies: Revascularisation etc.



Roberts (2010)



Feldmann (2005)



Goldstein (1998)

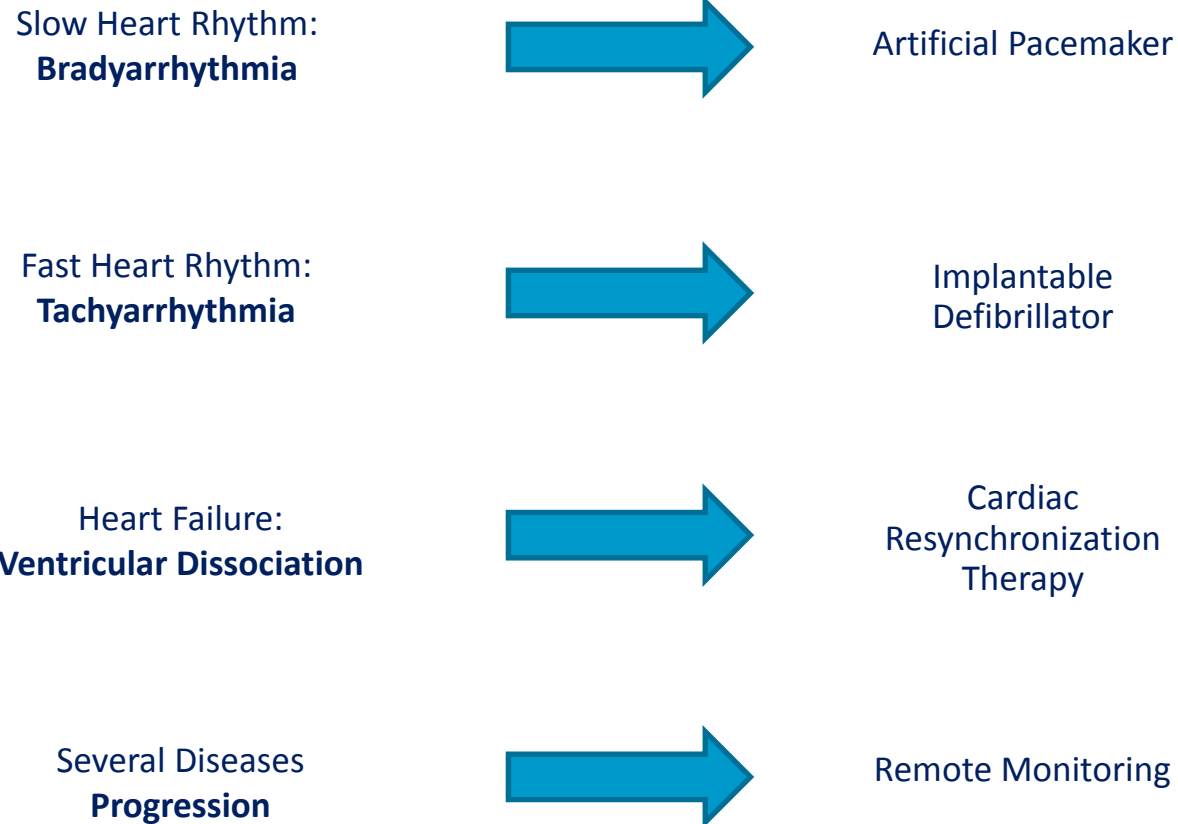
- **Types of surgical procedures:**
 - Elektrophysiological testing, HF ablation
 - Valve substitution, vessel surgery, cardiomyoplasty
 - Cardiac transplantation (including remote monitoring)
 - Cardiac assist devices (temporarily, permanently)

Medication Therapy: Types of Relevant Drugs

- **β Blockers:**
 - Decrease of adrenergic activation
- **ACE Blockers, Diuretics:**
 - Maintenance of fluid status
- **Antiarrhythmics:**
 - Influence on myocardial status

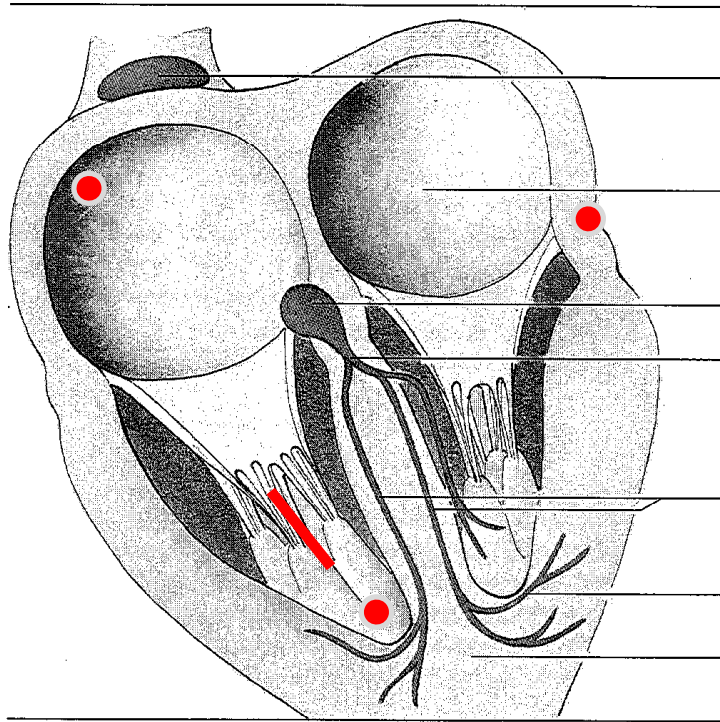
Topics of analysis e. g.: Monitoring of medication („patient compliance“)

Elektrotherapy of the Heart: Cardiac Rhythm Management



Example: Modern Electrotherapy

Three Chamber Defibrillator with Remote Monitoring



Klinke/Silbernagel (1994)

- Measurement of iEGM
- Includes activity sensor
- Stimulation impedance
- Cardiac resynchronization
- Defibrillation (ventricles!/atria?)
- Thoracic impedance (heart failure)
- Remote monitoring
- Pacemaker for backup

Scope and Consequences of Heart Disease

- **Prevalence of Heart Disease:**
 - Atrial Fibrillation 1%-10%, growing with age, many comorbidities
 - Sudden cardiac death: >100000 annual cases (Germany)
 - More than 10 mio. Europeans suffering from heart failure
- **Implant Statistics:**
 - 100000 surgeries due to pacemaker systems, CRT increasing (DHR 2008)
 - ~10000 ICD implantations (2006), poor statistics, increasing
 - Proportion of remote monitoring: 22% ICD and 7% pacemaker (2007)
- **Important Research Topics:**
 - Early detection of disease / risk stratification
 - Increase of scope of application of electrotherapy
 - Full use of modern technological achievements (remote monitoring)