

UiO : Department of Physics
University of Oslo

FYS 4250

Lecture 15





Footage.shutterstock.com



Tv2.no

A forty-four year old man falls to the ground in the street a sunny day in August. He is unconscious, no regular breathing, and he does not react to any kind of stimulus. The skin is pale, cold and dry, and the left leg is placed in an unnatural position. You are the first and apparently only person who see the incident.

Case 15



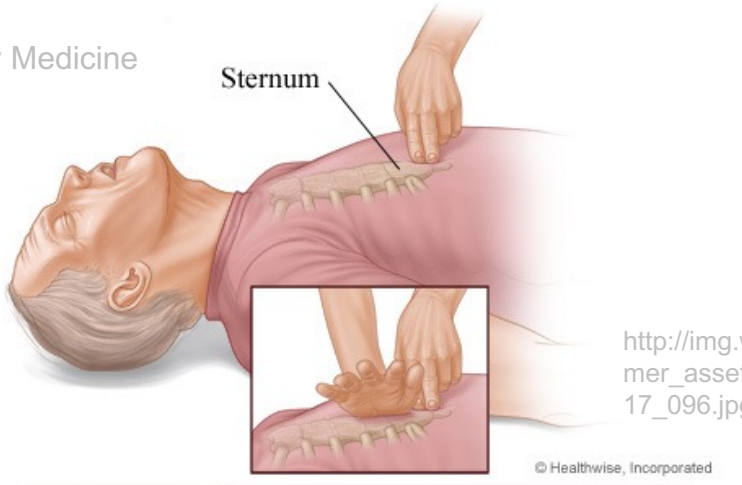
- First of all, dial 113 for help!
- Then, ABC

A- Airways. Free airways, head tilt and chin-lift. Observe the patient: color (pink vs cyanotic), patency of airway, stridor, tracheal deviation.

B- Breathing. Look, listen, and feel for air movement and chest rising. Resuscitation, mouth-to-mouth

C-Circulation. Assess pulse and blood pressure. If pulseless, chest compressions.

Source: Case files Emergency Medicine

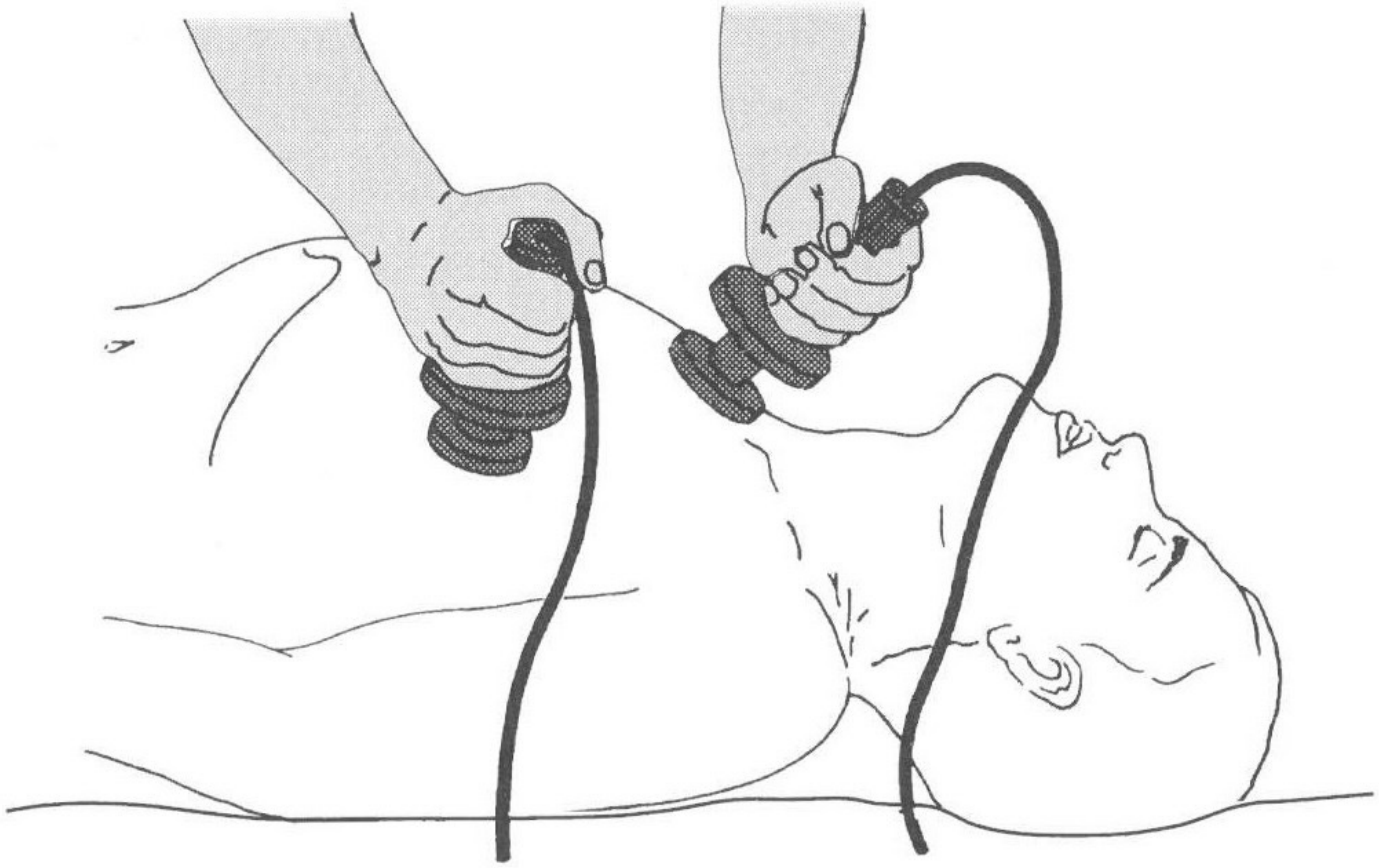


http://img.webmd.com/dtmcms/live/webmd/consumer_assets/site_images/media/medical/hw/hwkb17_096.jpg



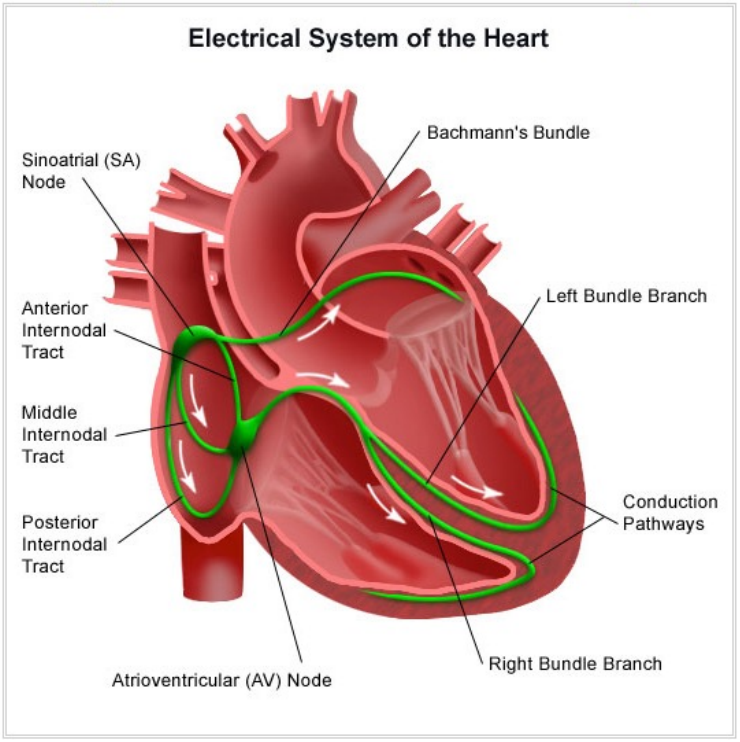
What is the first device that the ambulance will use?

Defibrillator (so-called heart starter)



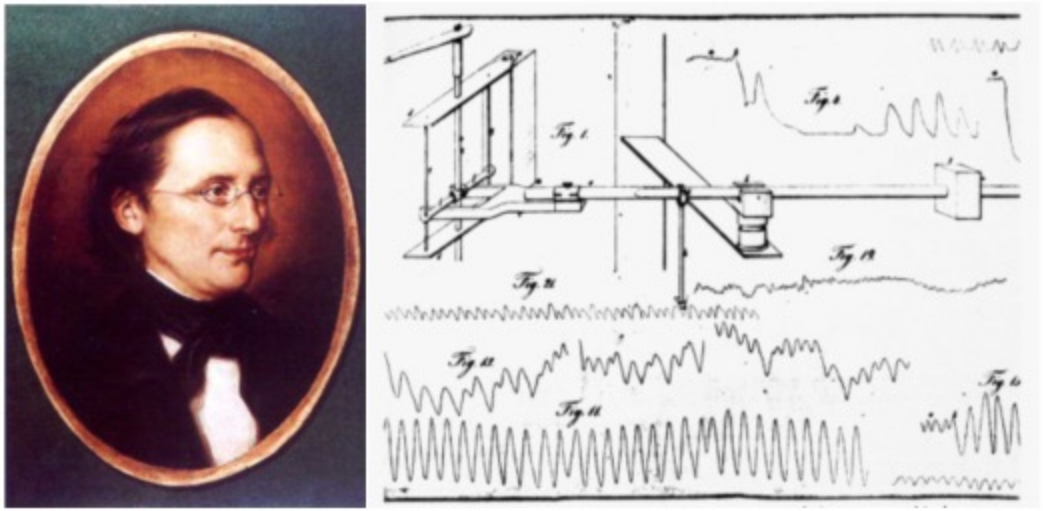
Figur 3:50. Extern hjärtdefibrillering.

Electric system of the Heart



http://www.ohsuhealth.com/htaz/cardiac/anatomy_and_function_of_the_hearts_electrical_system.cfm

Short history



Carl Ludwig (1816-1895) and his discovery of electrical stimulus-induced ventricular fibrillation. (M. Hoffa & C. Ludwig Einige neue Versuche uber Herzbewegung. Zeitschrift Rationelle Medizin 9:107-144, 1850)

Short history

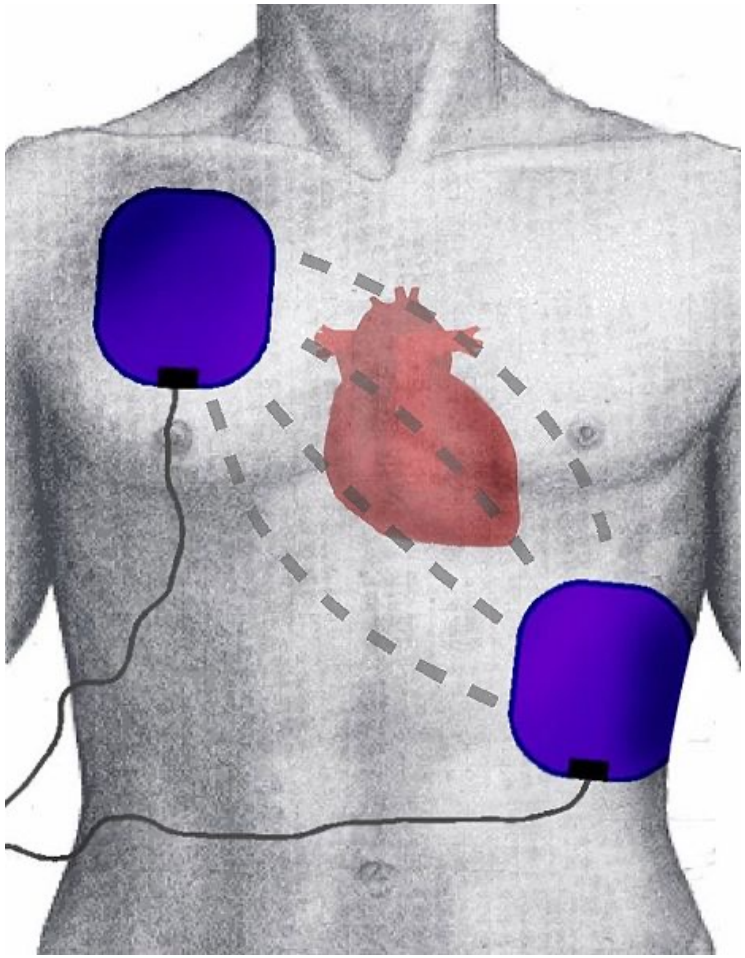
1947 – first patient saved



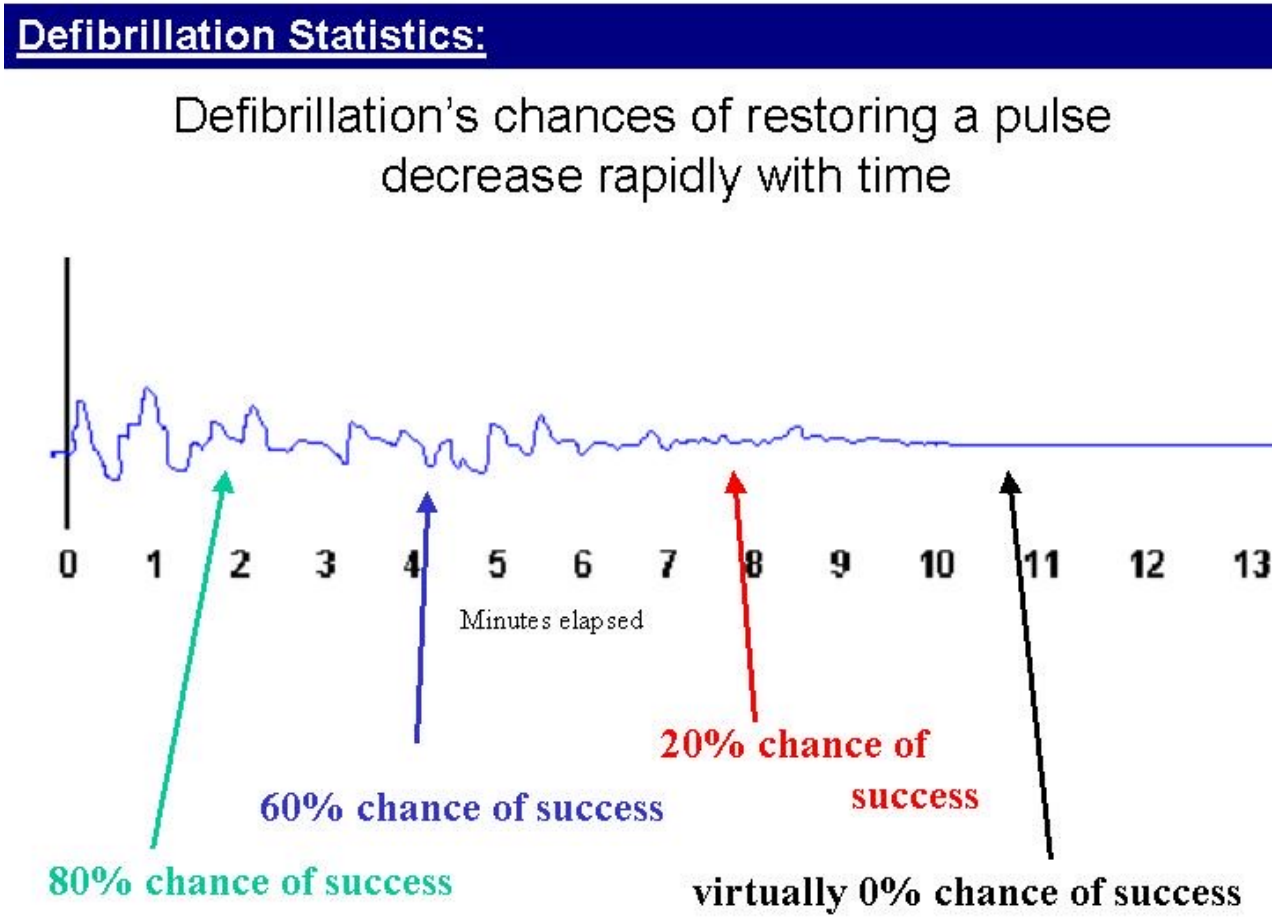


Claude S. Beck and his first defibrillator
Courtesy to Allen Memorial Medical Library, CWRU

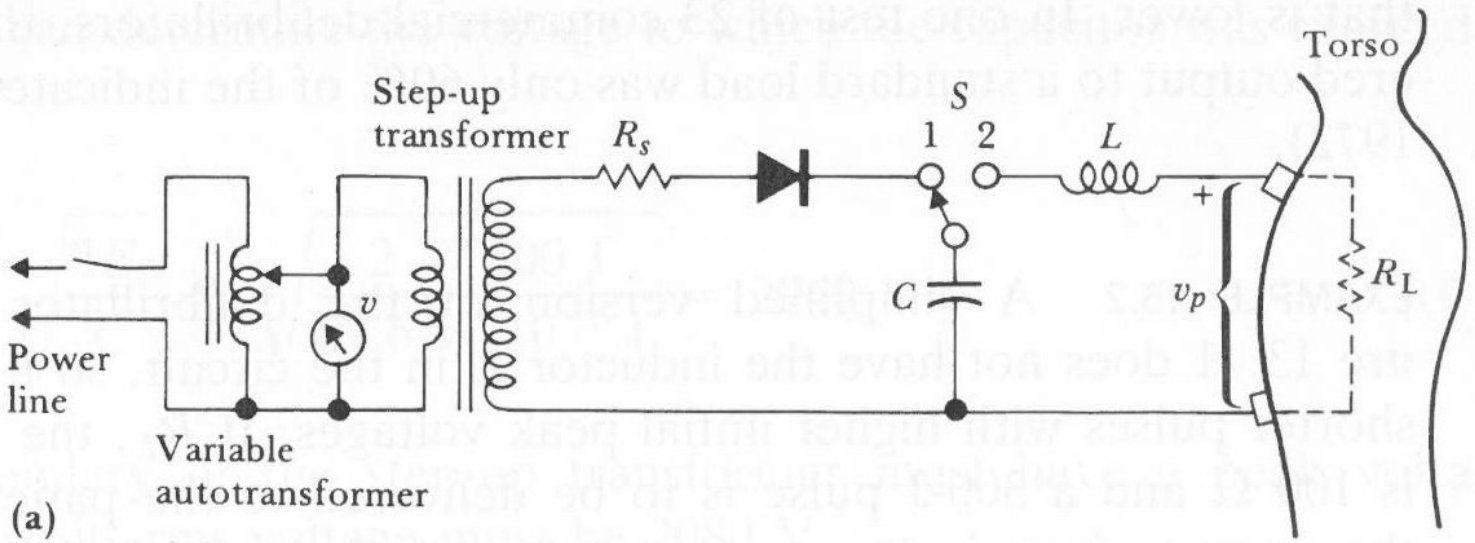
Defibrillation



Defibrillation

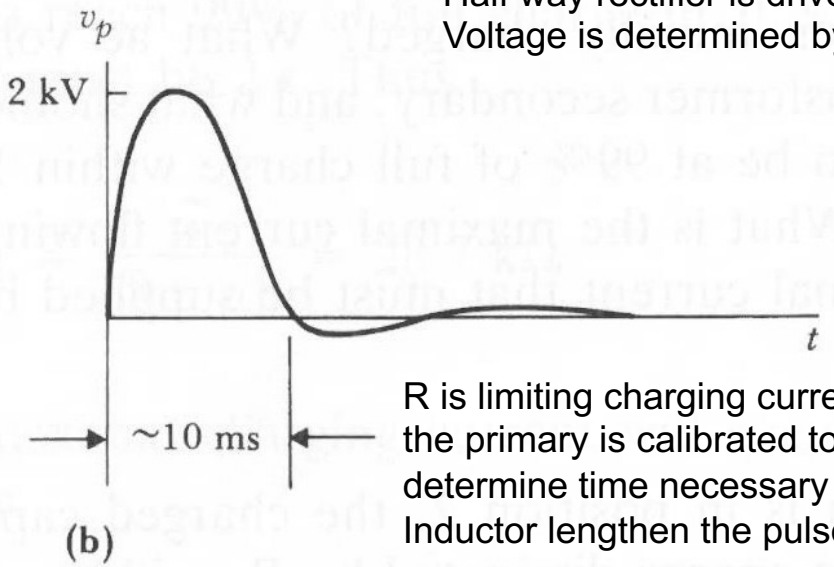


www.lessstress.com/



Half way rectifier is driven by a step-up transformer to charge capacitor C. Voltage is determined by a variable autotransformator in the primary circuit

Apparatus



R is limiting charging current to protect circuit components, an AC voltmeter across the primary is calibrated to indicate energy stored in the capacitor. (Also helps to determine time necessary to achieve full charge on capacitor.).
Inductor lengthen the pulse, producing a waveshape.

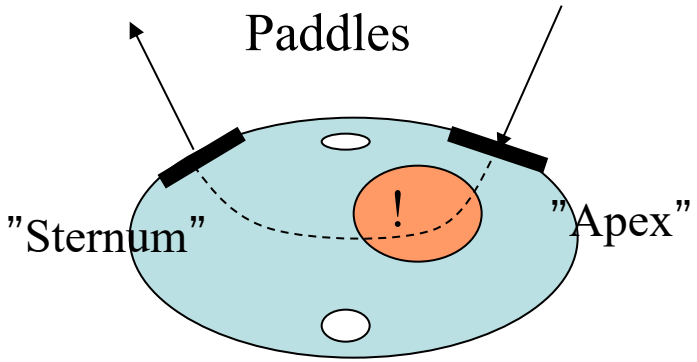
Figure 13.11 (a) Basic circuit diagram for a capacitive-discharge type of cardiac defibrillator. (b) A typical waveform of the discharge pulse. The actual waveshape is strongly dependent on the values of L, C, and the torso resistance R_L.

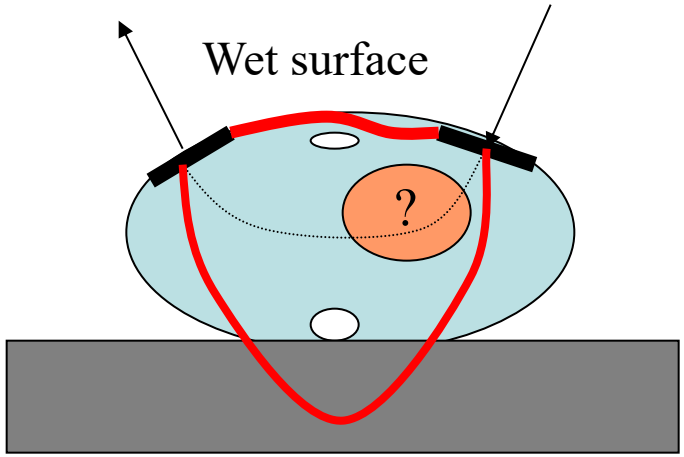
Defibrillator

Zoll AED Plus



Current pattern in the thoracic volume during defibrillation





Defibrillation, typical limits:

Current density 0,6A/cm^2 intracardial or energy 5 J/kg body weight

R_t: 20 - 200 ohm, I_m: 5- 60 A, V_m: 1000 - 6000 V

Ohms law: $V_m = R_t * I_m$

Internal and external electrodes

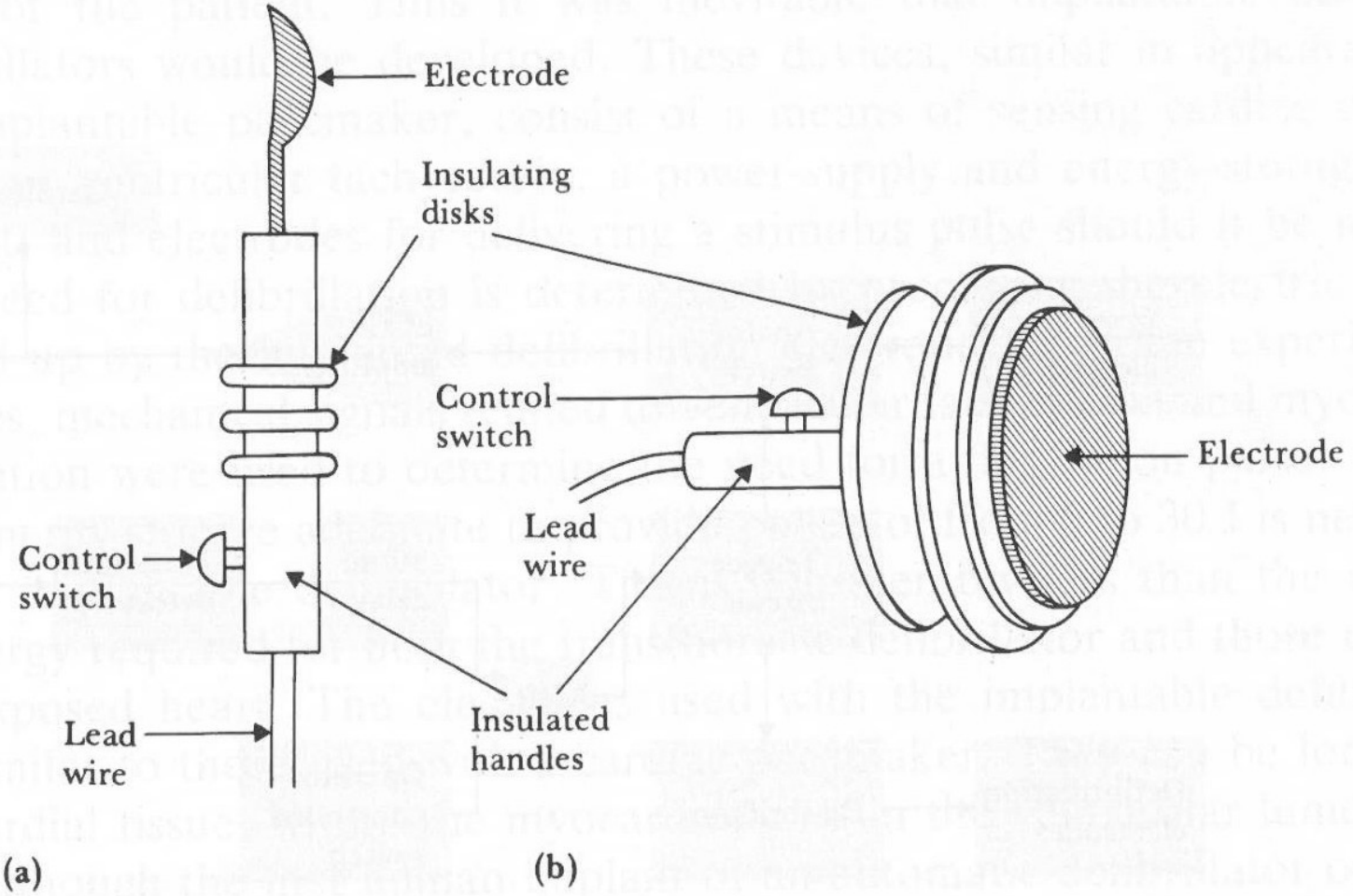
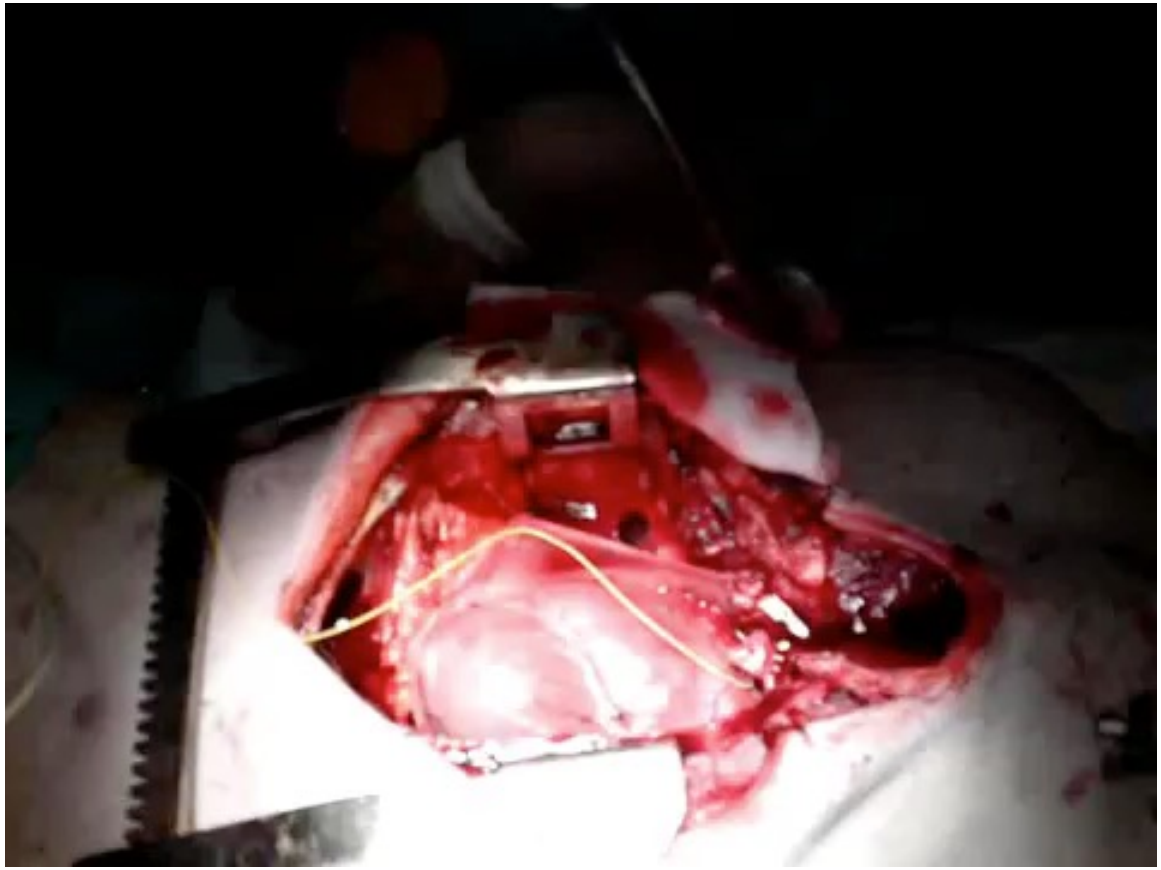


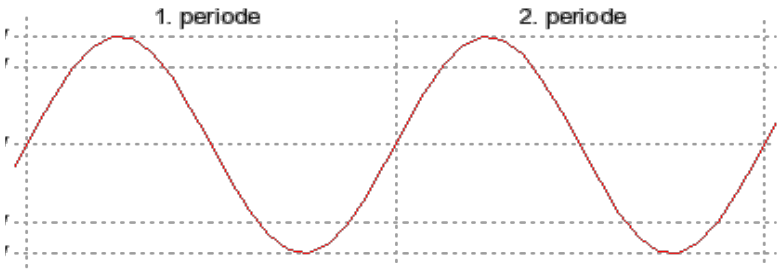
Figure 13.13 Electrodes used in cardiac defibrillation (a) A spoon-shaped internal electrode that is applied directly to the heart. (b) A paddle-type electrode that is applied against the anterior chest wall.

Defibrillation of the heart



Biphasic defibrillator

- Turns the current path (one syclus = ca 10 ms)
- Less energy consumption -> less risk of fire damages and injuries in myocard
- Higher successrate (90% instead of 60% using monophasic defibrillation[1])



1. Heart Smarter: EMS Implications of the 2005 AHA Guidelines for ECC & CPR pp 15-16

Exercise

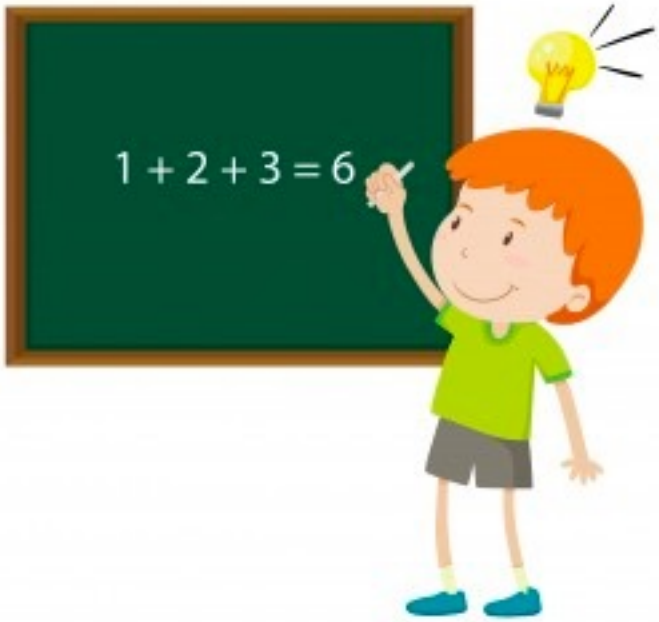
Form groups of 2 or 3 students, and discuss:

- The defibrillator electrodes are distinctly labeled ”Apex” and ”Sternum” for professionals, and with figures for consumer market. Will it be critical if the two electrodes are switched?





http://integrativeosteopathy.com.au/wp-content/uploads/2015/08/Exercise.jpg

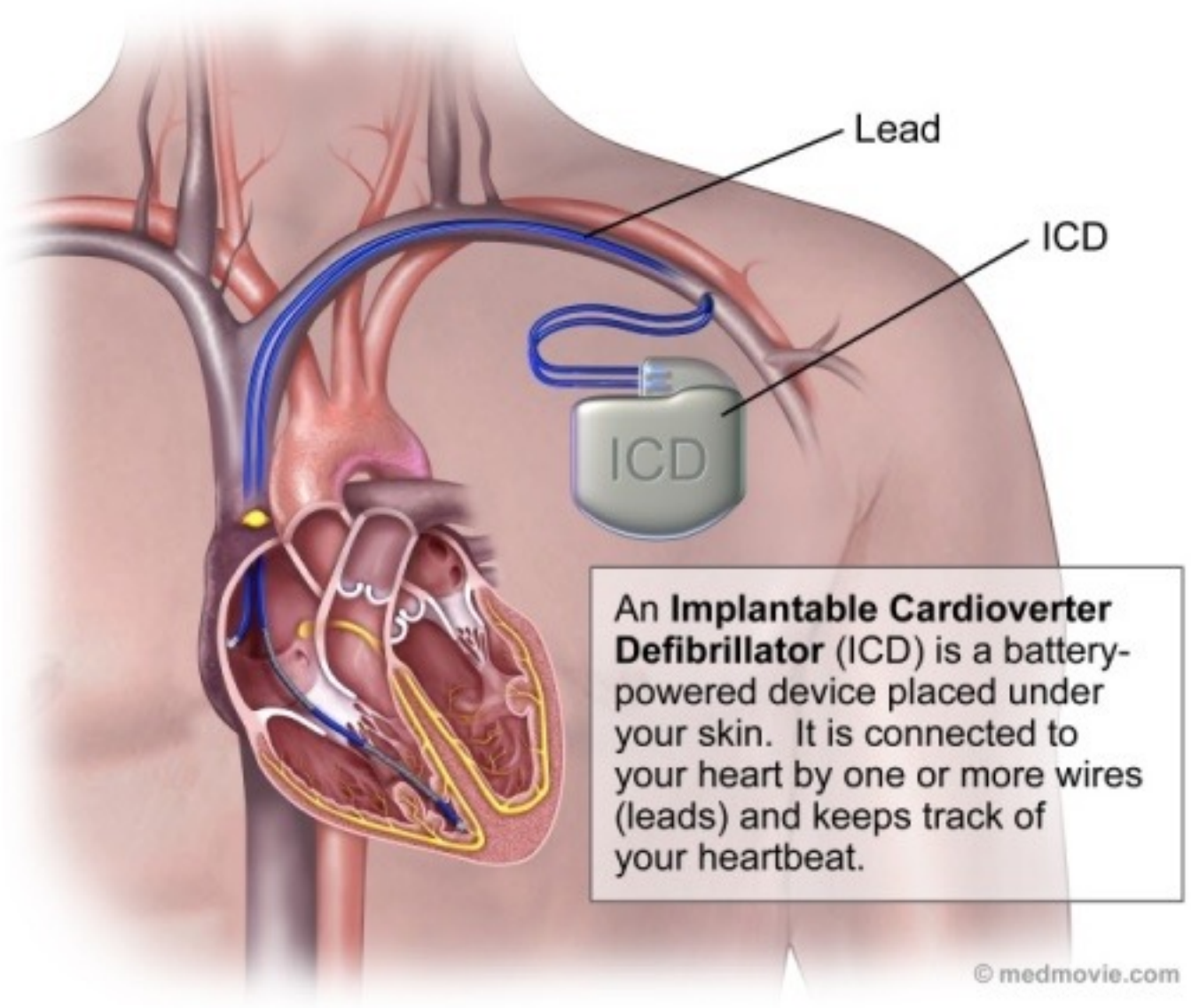


Answer

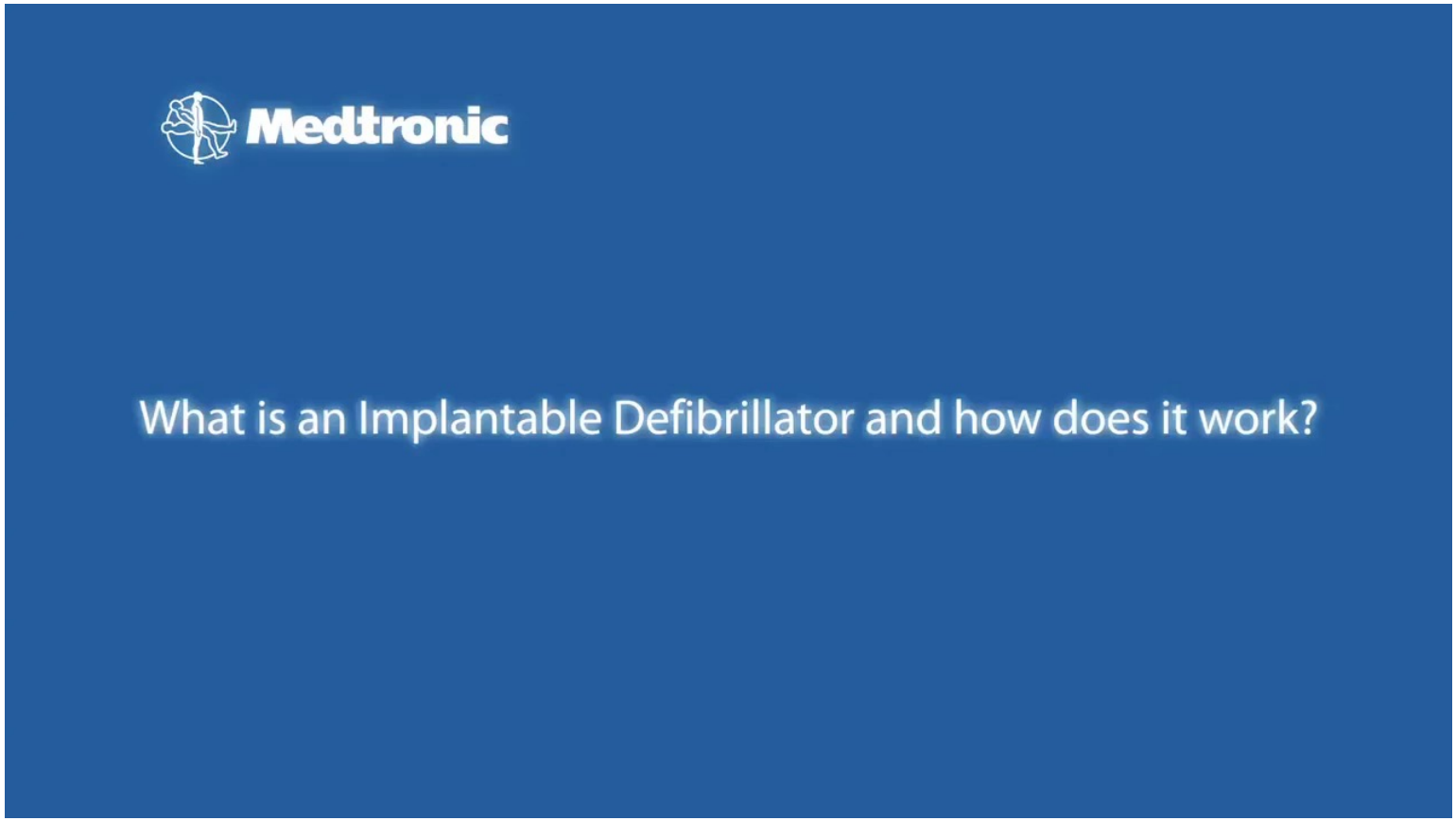
As long as the defibrillator is biphasic, and as long as one of the electrodes is placed on sternum and the other on apex, this will not matter for the current applied.

But, it will matter for the ECG that is monitored by most defibrillators. For the professional semi- or manual defibrillators the only result is that the ECG is turned upside down. For the fully automatic defibrillators the result might be that the ability to detect shockable rhythm-disturbances can be altered in worst cases.

Implantable Cardioverter Defibrillator (ICD)



Implantable defibrillator



Electro-conversion of atrial fibrillation (synchronous defibrillation)

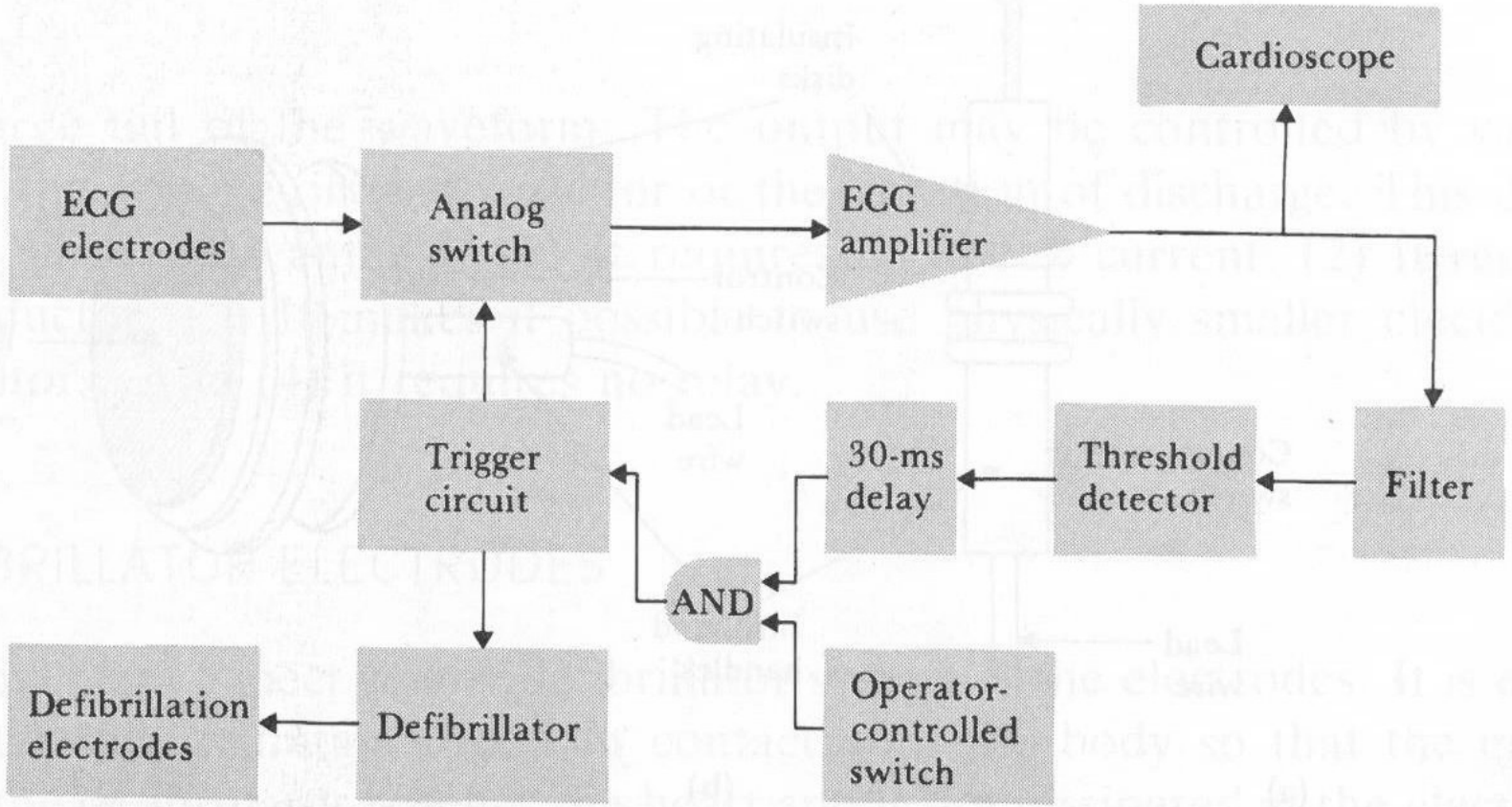


Figure 13.14 A cardioverter The defibrillation pulse in this case must be synchronized with the R wave of the ECG so that it is applied to a patient shortly after the occurrence of the R wave.

Hitting the T-wave may cause ventricular fibrillation. Normally not a problem unless the patient suffers from atrial arrythmia

Electro conversion of atrial fibrillation

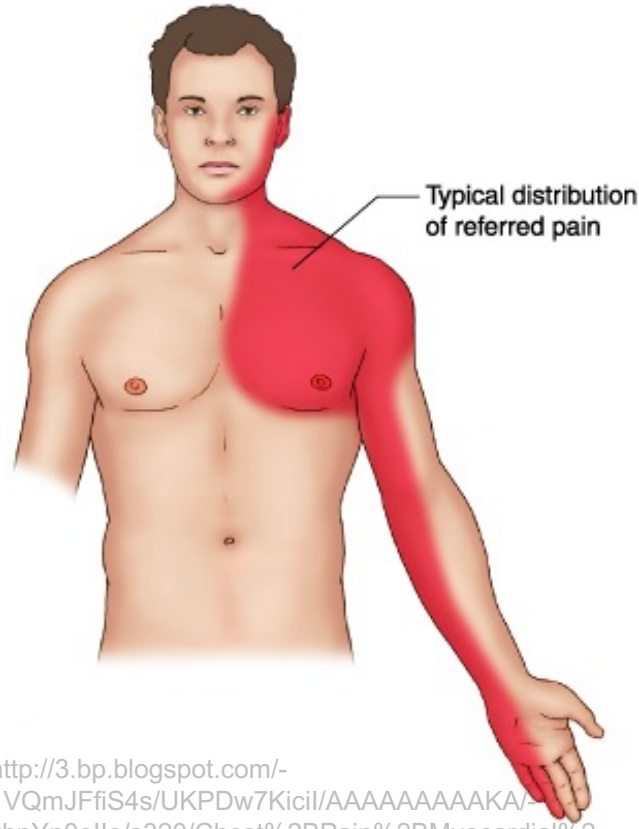


Case 15



- The defibrillation procedure is successful, and the patient is transported to hospital in the ambulance. His medical history shows that he is a long-time smoker, has beginning diabetes II, and has been through a surgical removal of a lung tumor seven years ago. This tumor turned out to be malign, and a part of the lung tissue around the tumor and the adjacent lymph nodes were removed as well.

- Half a year ago he decided to seek his family doctor as he felt a continuously increasing fatigue and dizziness, and he was scheduled for a PET-examination the day after the incident on the street. Upon admission to hospital, the doctors first order an angiography because he shows the typical signs of a heart infarction and they expect that an infarction in the heart or another serious structural change was the origin of the heart fibrillation.

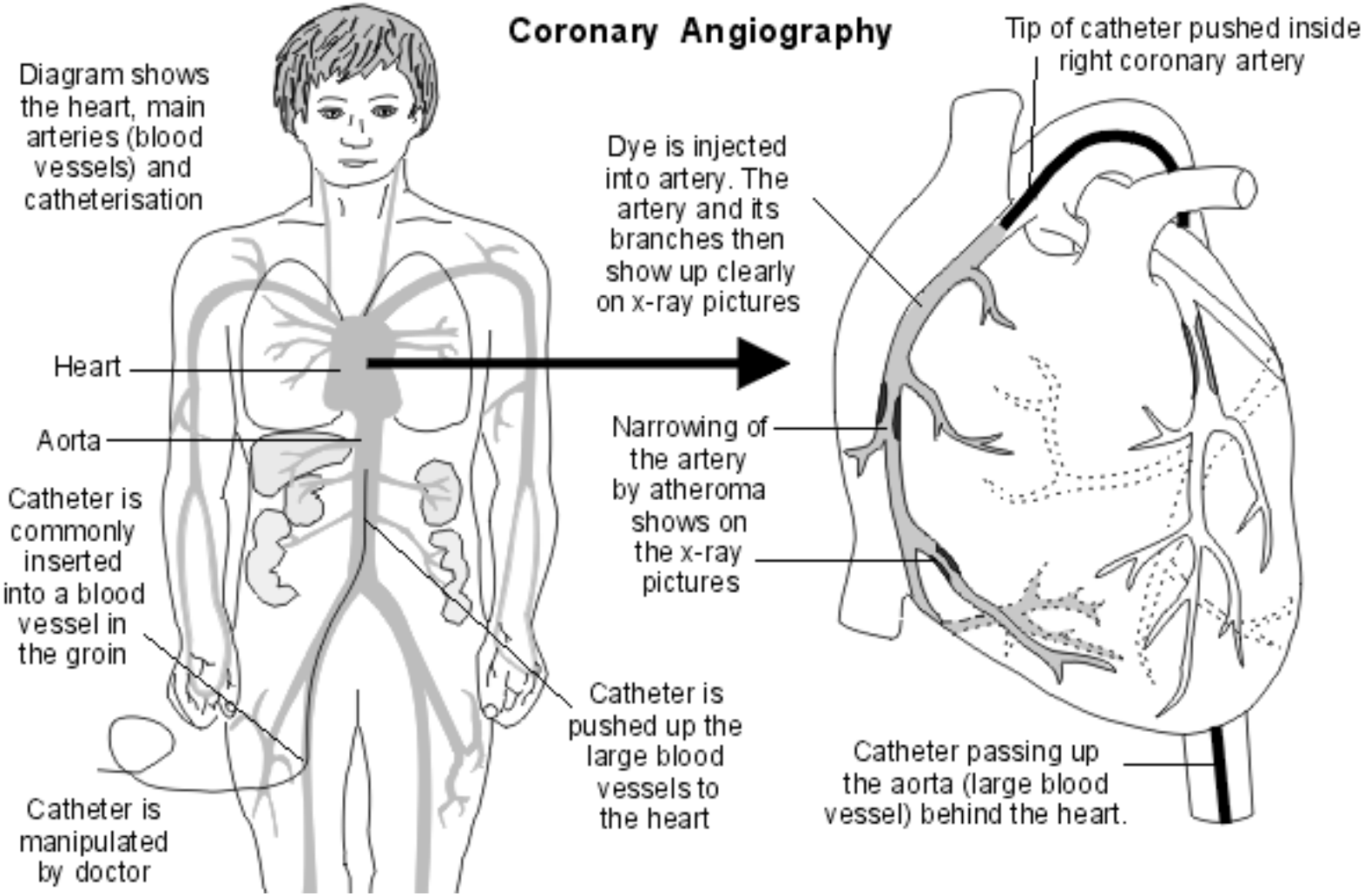


http://3.bp.blogspot.com/-1VQmJFfiS4s/UKPDw7KiciI/AAAAAAAAAKA/-xbpYn0oIIo/s320/Chest%2BPain%2BMyocardial%2BInfarction.jpg

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Case 15





Case 15



- The angiography shows surprisingly enough no signs of constrictions in the coronary arteries, and they conclude that there has been no heart infarction. The examination continues with a PET-scan in order to reveal possible cancerous cells in the body.

Gamma Camera

- A camera for nuclear imaging. The most used so far was invented by H. Anger in the 1960's (The Anger camera)



http://img.medicalexpo.com/images_me/photo-g/70717-3803791.jpg

Principle: The patients drinks a cocktail including a radioactive tracer bound to a sugarlike molecule. Cells with high consumption of energy (e.g. Cancerous cells) will take up more of the tracer than healthy tissue, this can be measured with a gamma camera

Scintillation-detector

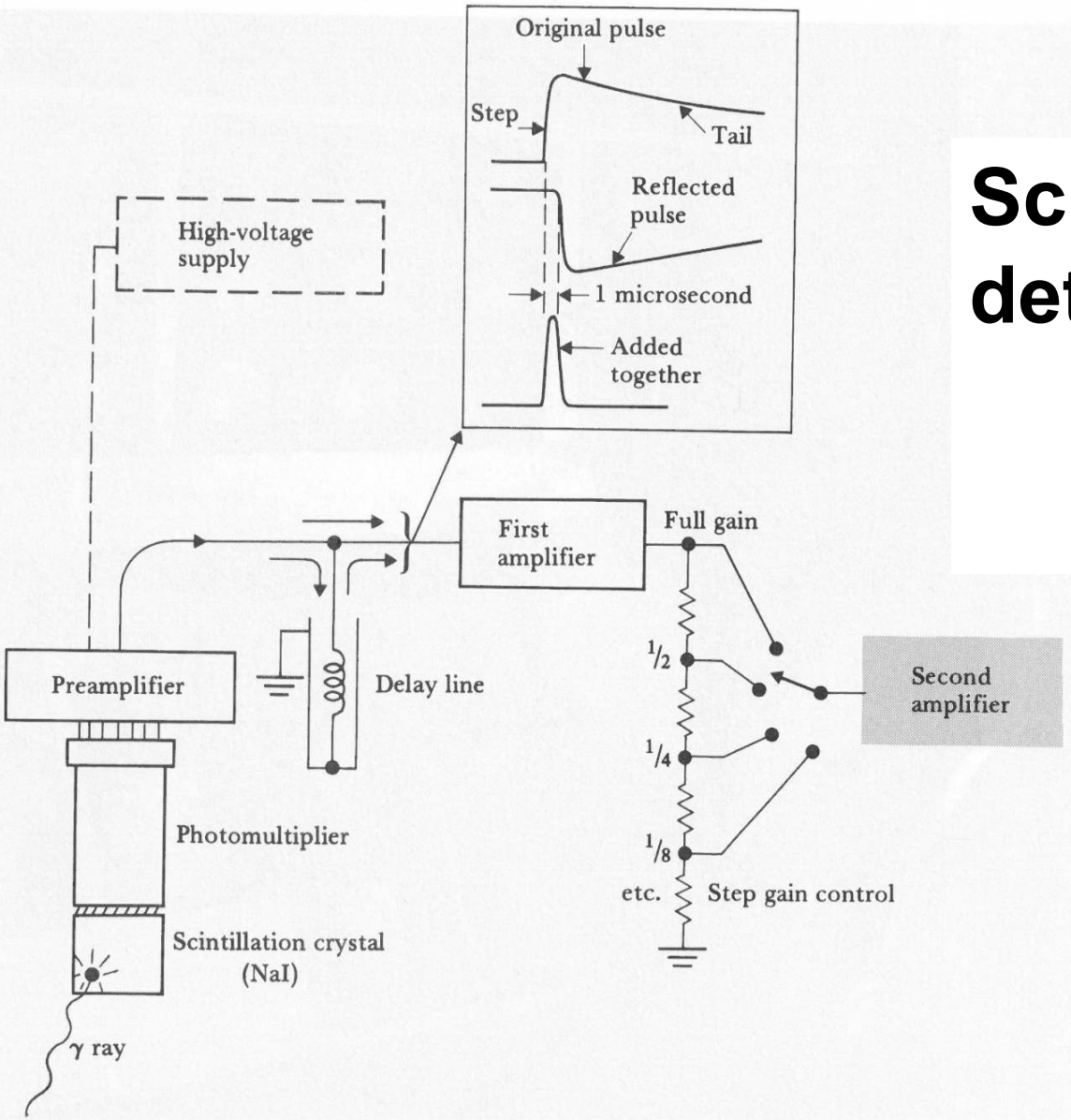
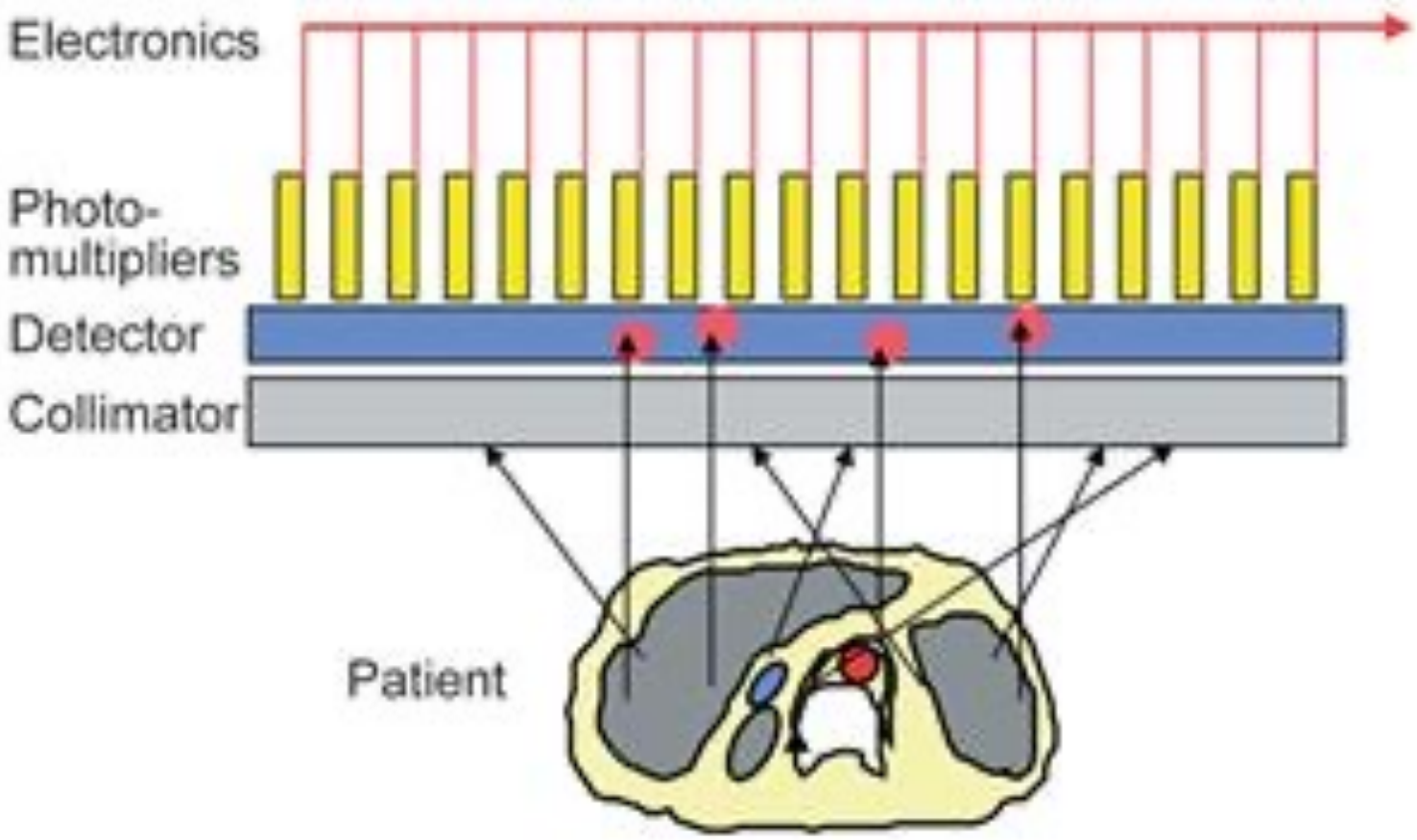


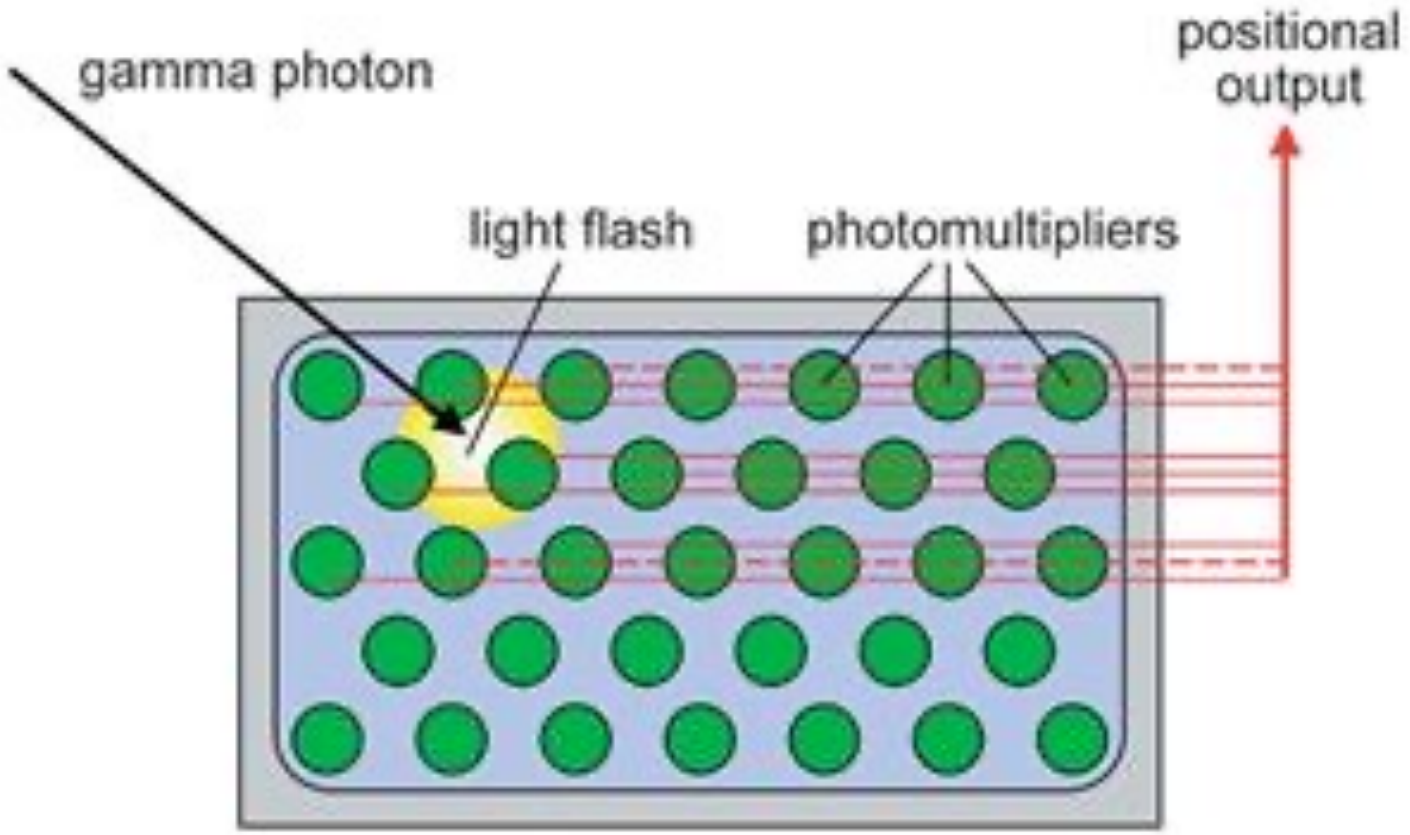
Figure 12.23 Basic implementation of a NaI scintillation detector, showing the scintillator, light-sensitive photomultiplier tube, and support electronics. (From H. N. Wagner, Jr., ed., *Principles of Nuclear Medicine*. Philadelphia: Saunders, 1968. Used with permission of W. B. Saunders Co.)

Anger camera

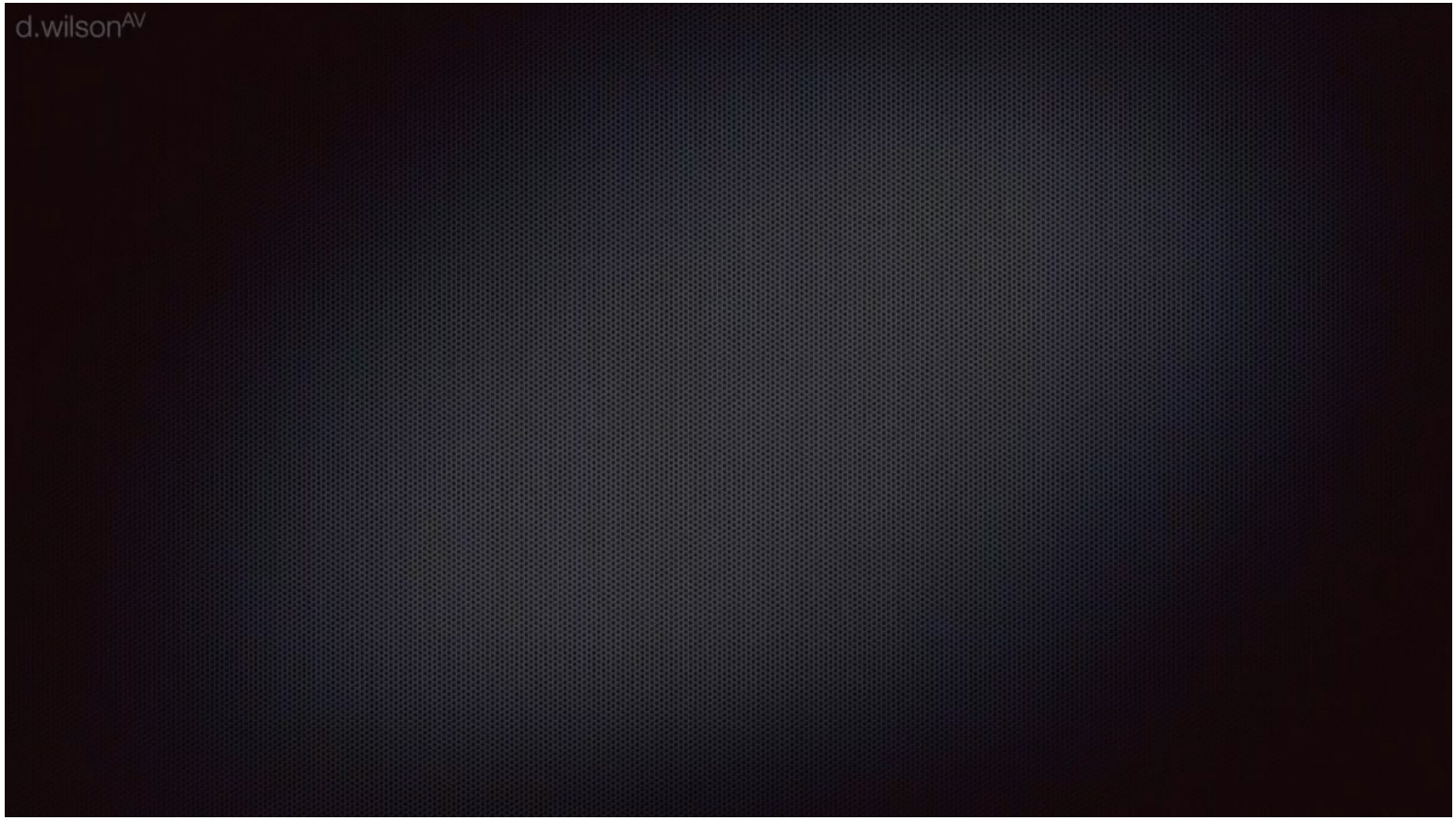


Photons with a proper direction are let through the collimator, into the detector and photomultipliers

Anger Camera (cont.)



The gamma camera visualized



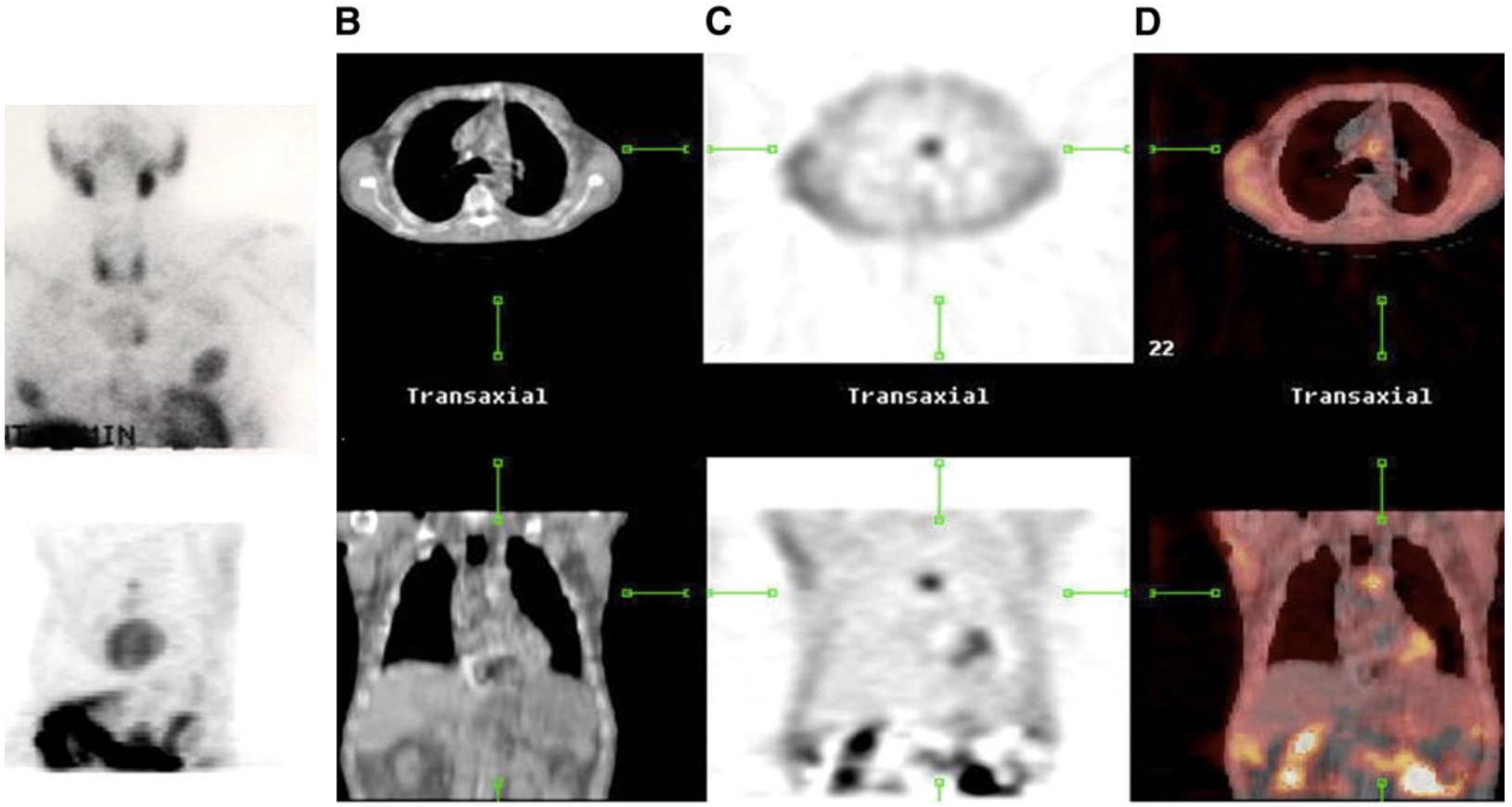
SPECT- imaging

Single photon emission computer tomography, systematic use of gamma camera



Image: GE Healtcare

SPECT



Source: http://tech.snmjournals.org/content/36/1/1/F9.large.jpg

Line spread and MTF

Response of a gamma camera to a line source of radioactivity. Line-spread function of camera was generated by summing over one dimensjon of the digital image aquired in nuclear-medicine computer -> Fourier transformed to generate modulation transfer function

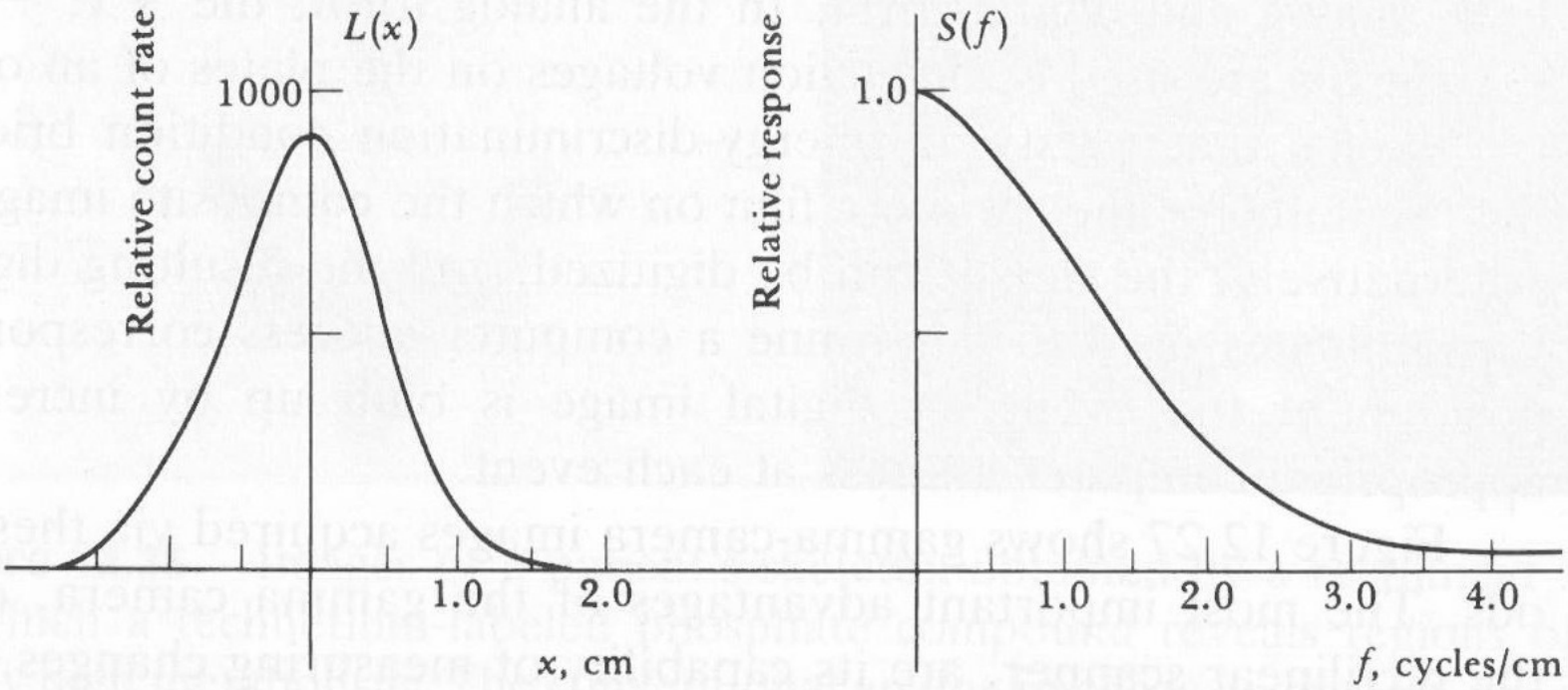


Figure 12.28 Line-spread response function obtained in a gamma camera under computer control, together with the corresponding modulation transfer function.

PET camera

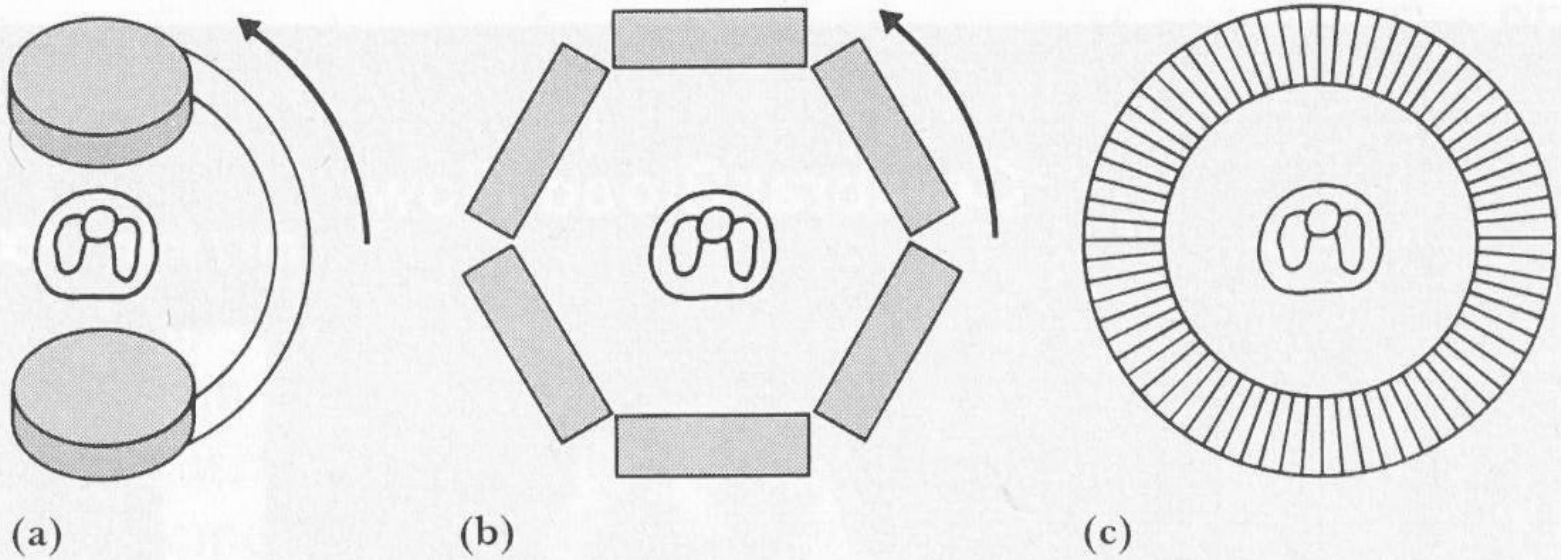


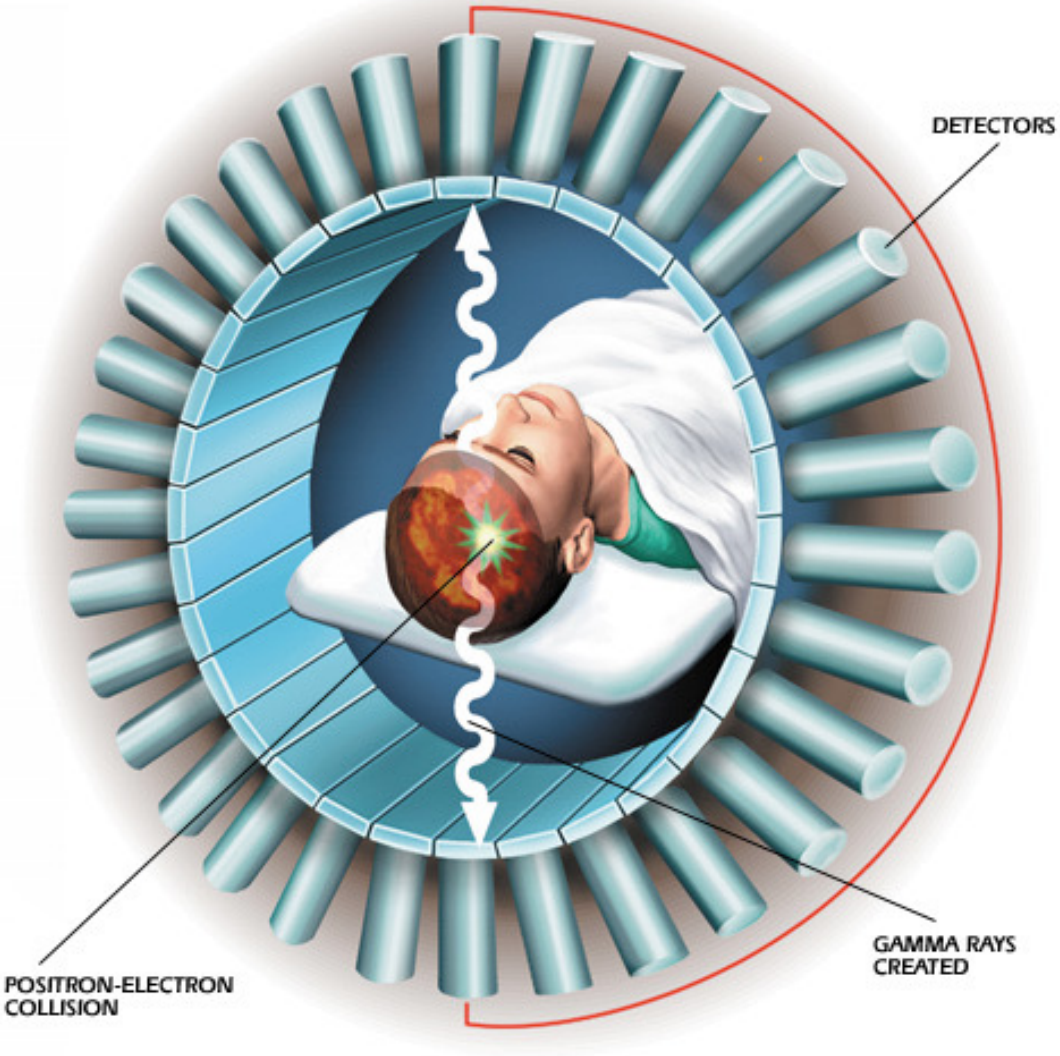
Figure 12.29 Evolution of the circular-ring PET camera (a) The paired (b) the hexagonal ring cameras rotate around the patient. (c) The circular assembly does not rotate but may move slightly—just enough to fill in the between the detectors. The solid-state detectors of the ring camera are integ with the collimator and are similar in construction to detectors used ir machines.

PET/CT scanners



Image: http://2nznub4x5d61ra4q12fyu67t.wpengine.netdna-cdn.com/img/4363ct1.jpg

PET Scan

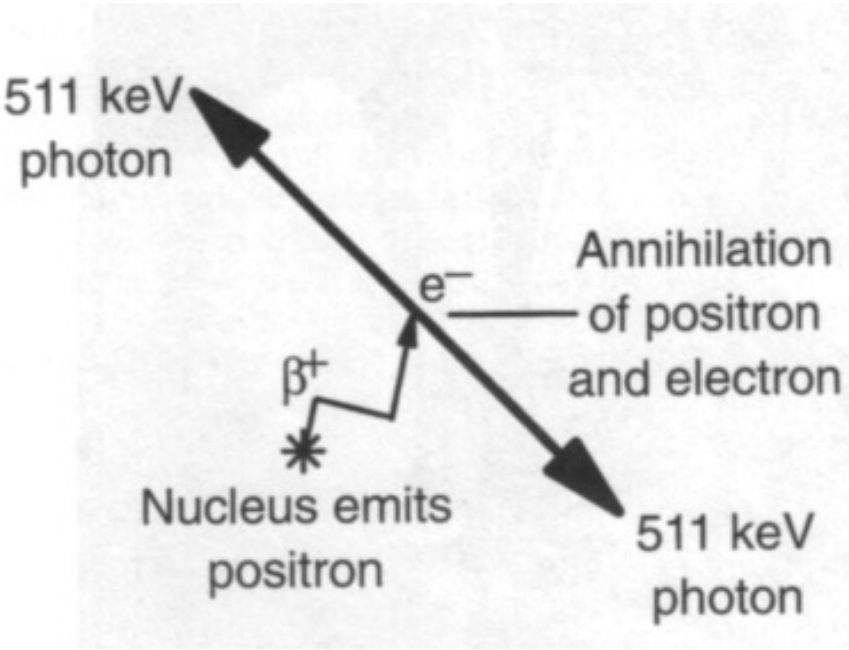


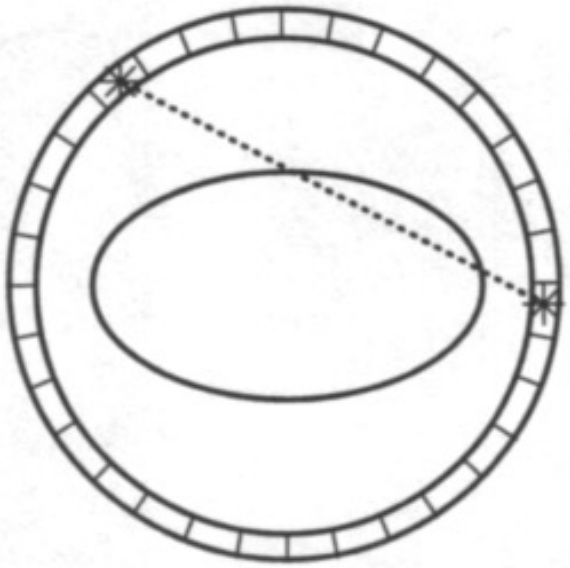
Measured quantity is concentration of positron emitter. To obtain actual concentration -> calibrate and measure the performance of the machine



Annihilation coincidence detection

- Emitted positrons lose their kinetic energy by causing excitation and ionization
- A positron that has lost most of the energy will interact with an electron by an ***annihilation***
- This annihilation will convert the mass of the electron-positron pair into two 511-keV photons, emitted in contrary directions


511 keV
photon
e⁻
Annihilation
of positron
and electron
β+
Nucleus emits
positron
511 keV
photon



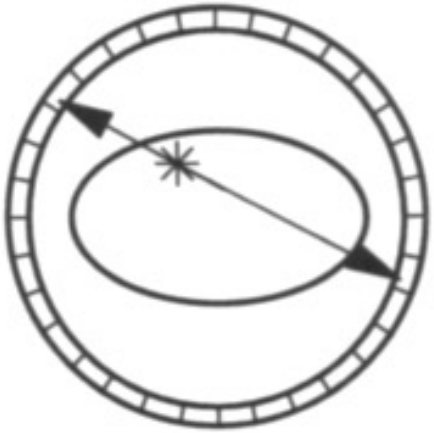
Annihilation coincidence detection

- If a simultaneous photon is registered in two different detectors, the annihilation came into being along a straight line between the two detectors (LOR). The electronics within a scanner detects the simultaneous hits in a process called annihilation coincidence detection
- When two simultaneous hits have been detected, a line between the two detectors is calculated

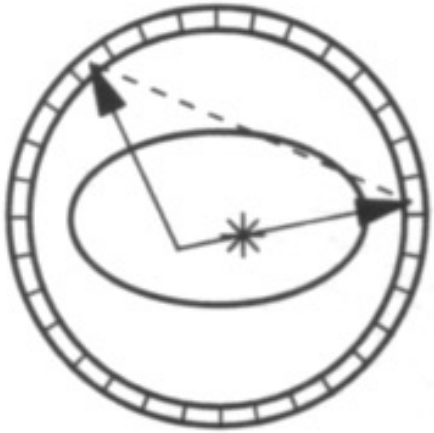
True, random, and scatter coincidences

- A *true coincidence* = detection is the result of a single nuclear annihilation
- A *random coincidence* = photons from different nuclear transformations are detected simultaneously at the detectors. May give erroneous results.
- A *scatter coincidence* = one or both photons from a single annihilation are scattered in different directions but still detected in the detector

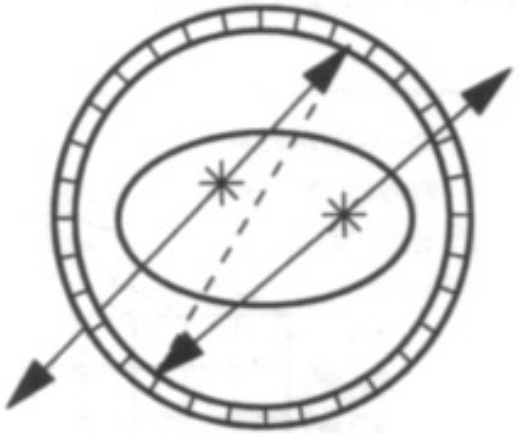
True



Scattered



Random



Exercise

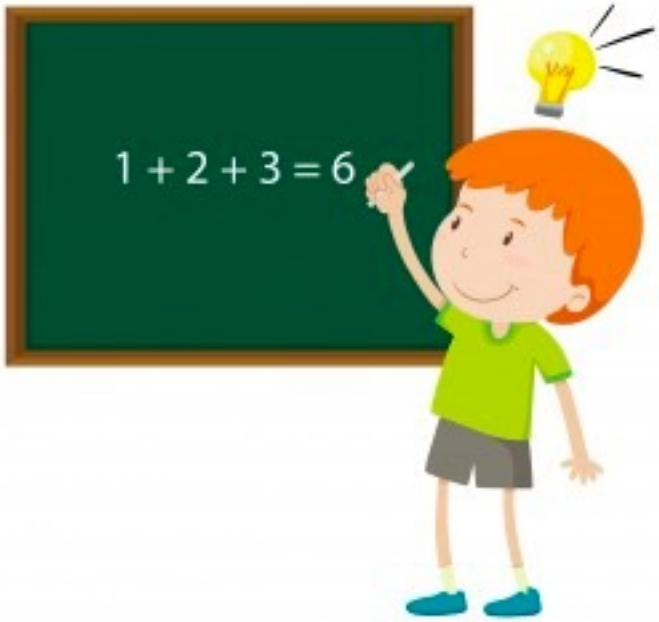
Form groups of 2 or 3 students, and discuss:

- All x-ray systems, including gamma cameras and SPECT, use collimators. Explain why most modern PET-scanners don't



http://integrativeosteopathy.com.au/wp-content/uploads/2015/08/Exercise.jpg

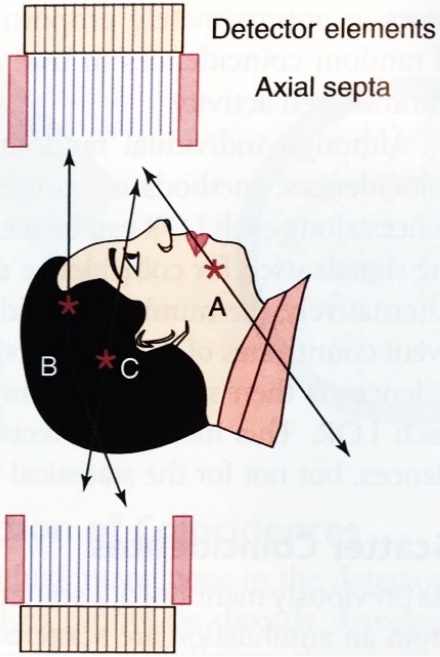
Answer



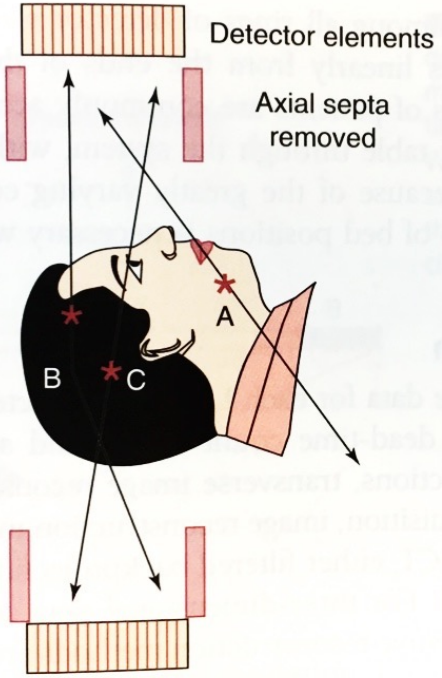
Annihilation coincidence Detection (ACD) establish the trajectories of detected photons which is the same function as the collimator do. But there are two great advantages with ACD compared to collimation:

1. *ACD waste much less photons than the collimator. If PET-scanners should use collimators, the scantime or tracerdose would have to be increased*
2. *Collimation will loose spatial resolution as a function of distance from the detector, ACD do not*

2D vs 3D P scanner



■ **FIGURE 19-19** Side view of PET scanner illustrating two-dimensional data acquisition. The axial septa prevent photons from activity outside the field-of-view (**A**) and most scattered photons (**B**) from causing counts in the detectors. However, many valid photon pairs (**C**) are also absorbed.



■ **FIGURE 19-21** Side view of PET scanner illustrating three-dimensional data acquisition. Without axial septa, interactions from activity outside the FOV (**A**) and scattered photons (**B**) are greatly increased, increasing the dead time, random coincidence fraction, and scatter coincidence fraction. However, the number of true coincidences (**C**) detected is also greatly increased.

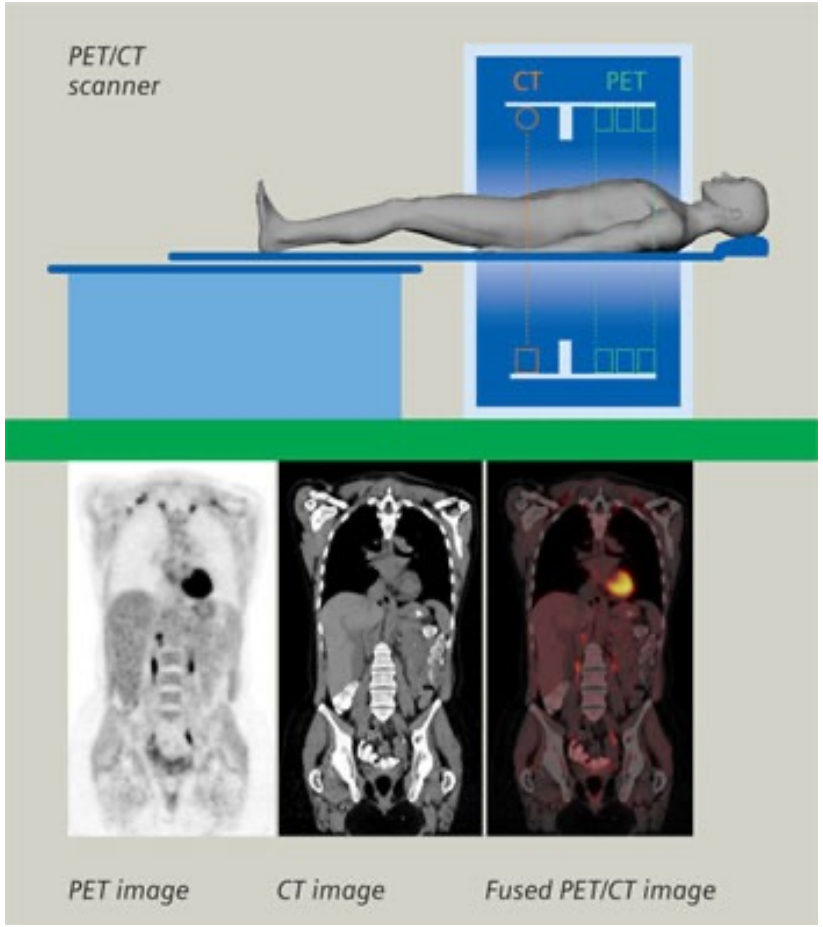
Source: Bushberg et al. The essential physics of Medical Imaging (2012)

Design of a PET scanner

- PET = scintillation crystals coupled to photomulitiplier tubes (PMT)
- The signals are then processed in pulse mode in order to find the position, energy and the timestamp for each interaction
- The energy levels can be used to discriminate between scatter coincidences and true coincidences
- Early PET scanners coupled each scintillation crystal to a single PMT
  - Size of individual crystal largely determined spatial resolution of the system
- Modern designs couple larger crystals to more than one PMT
- Relative magnitudes of the signals from the PMTs coupled to a single crystal used to determine the position of the interaction in the crystal

PET-CT

- Usually combined with CT in order to localize activity in the body



Scintillators

TABLE 19-2 PROPERTIES OF SEVERAL INORGANIC SCINTILLATORS OF INTEREST IN PET

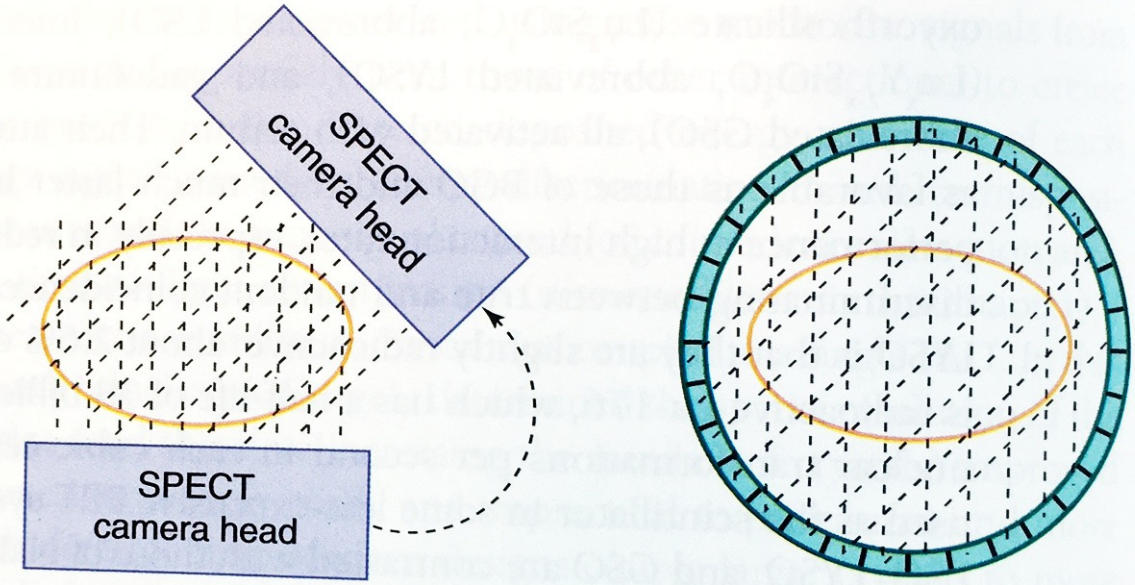
SCINTILLATOR	DECAY CONSTANT (ns)	PEAK WAVELENGTH (nm)	ATOMIC NUMBERS	DENSITY (g/cm^3)	ATTENUATION COEFFICIENT 511 keV (cm^{-1})	CONVERSION EFFICIENCY RELATIVE TO NaI
NaI(Tl)	250	415	11,53	3.67	0.343	100%
BGO	300	460	83,32,8	7.17	0.964	12%–14%
GSO(Ce)	56	430	64,14,8	6.71	0.704	41%
LSO(Ce)	40	420	71,14,8	7.4	0.870	75%

Decay constants, peak wavelengths, densities, and conversion efficiencies of BGO, GSO, and LSO (From Ficke DC, Hood JT, Ter-Pogossian MM. A spheroid positron emission tomograph for brain imaging: a feasibility study. *J Nucl Med* 1996;37:1222.)
LYSO(Ce) has a decay constant, peak emission wavelength, and relative conversion efficiency similar to those of LSO (Ce), but its density and attenuation coefficient are less. Its density and attenuation coefficient vary with the proportion of yttrium to lutetium. (Information on LYSO from Chen J, Zhang L, Zhu RY. Large size LYSO crystals for future high energy physics experiments. *IEEE Trans Nucl Sci* 2005;52(6):3133–3140.)

Source: Bushberg et al. The essential physics of Medical Imaging (2012)

SPECT vs PET scanner systems

■ **FIGURE 19-18** Acquisition of projection data by a SPECT system (**left**) and a PET system (**right**), showing how each system collects data for two projections. However, the PET system collects data for all projections simultaneously, whereas the scintillation camera head of the SPECT system must move to collect data from each projection angle.

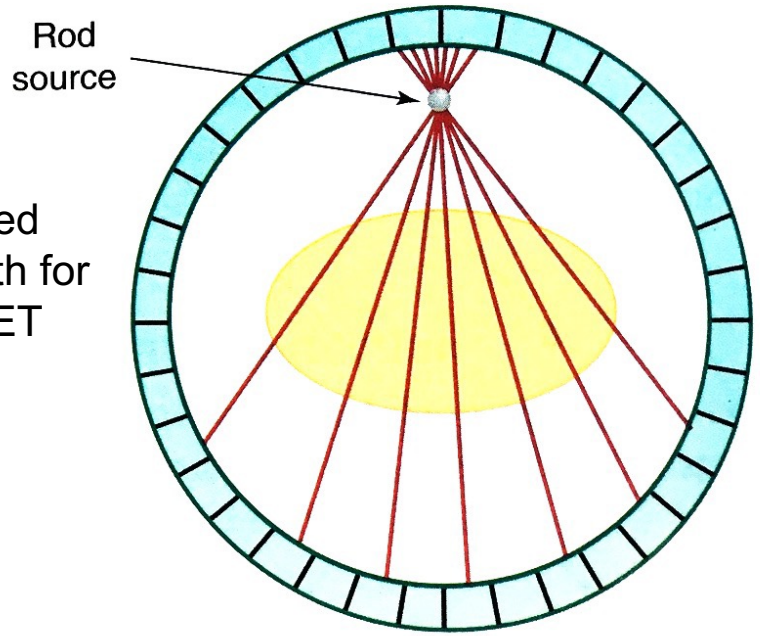


Source: Bushberg et al. The essential physics of Medical Imaging (2012)
Source: Bushberg et al. The essential physics of Medical Imaging (2012)

Some of the photons are lost on the way to the detectors, this is depending on the tissue they are penetrating. How can we correct for this?

Attenuation correction

■ **FIGURE 19-26** Rod source for attenuation correction in a dedicated PET system.



Attenuation coefficient for 511-keV annihilation photons in soft tissue is lower than photons emitted by most radionuclides, but the average path length for both to escape is much longer = Higher loss in PET

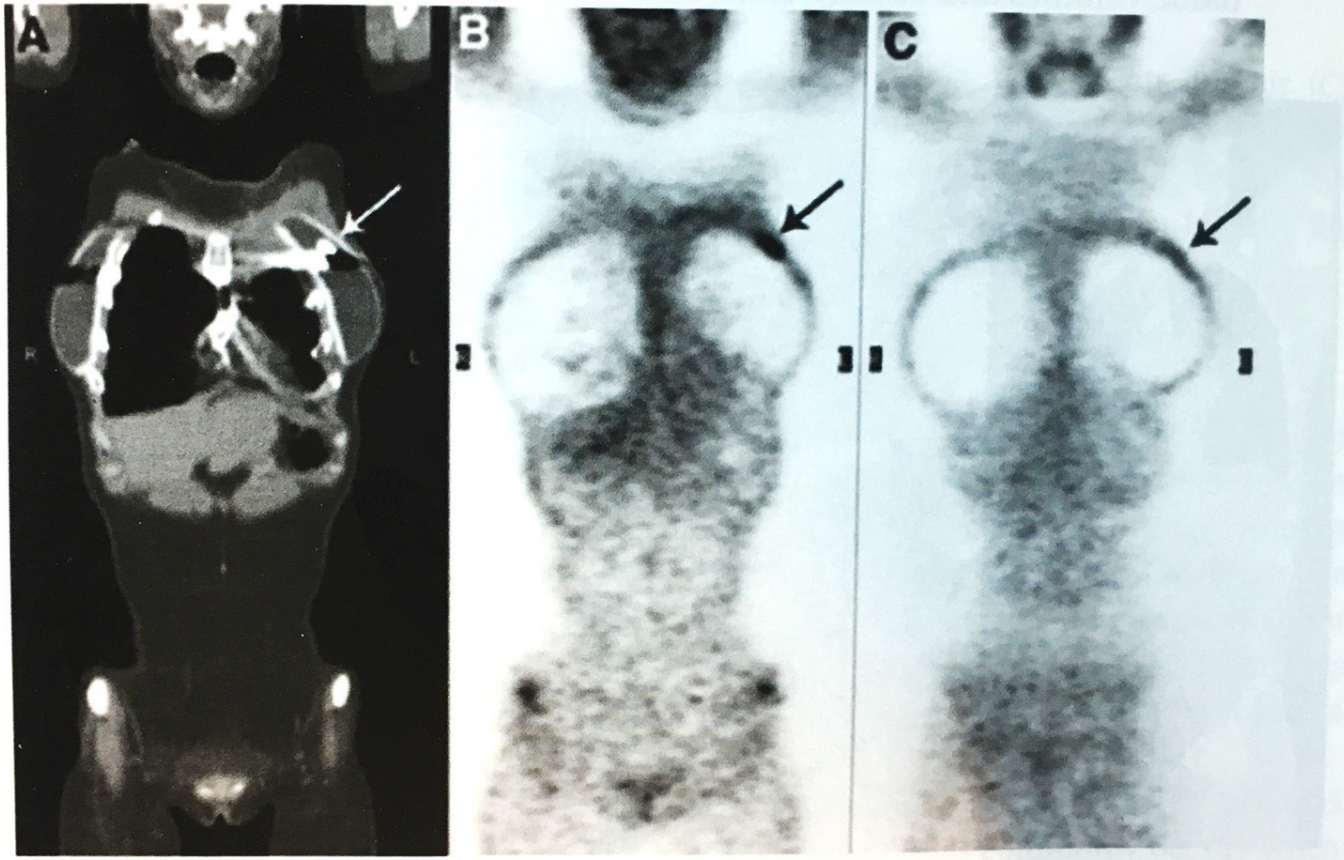
LOR = Line of radiation

Disadvantages – Increased imaging time
-Slightly increased dose
-Increased spatial noise
-Patient movement can give spatial misregistration between attenuation map and emission data when not aquired simultaneously

Today, CT is used for attenuation correction

Source: Bushberg et al. The essential physics of Medical Imaging (2012)

Attenuation correction



■ **FIGURE 19-29** Attenuation correction artifact caused by overestimation of attenuation by a metal object, in this case a body piercing. CT image (**A**) shows a streaking artifact at the location of the metal object on the left breast. Overestimation of attenuation causes the attenuation-corrected PET image (**B**) to display a falsely elevated concentration of F-18 FDG at the location of the metal object. Notice that that concentration of F-18 FDG is not elevated in the PET image (**C**) that is not attenuation corrected. (Images courtesy of Sureshbabu W,

Source: Bushberg et al. The essential physics of Medical Imaging (2012)

Comparison of SPECT and PET

Source: Bushberg et al. The essential physics of Medical Imaging (2012)

TABLE 19-5 COMPARISON OF SPECT AND PET

	SPECT	PET
Principle of projection data collection	Collimation.	Annihilation coincidence detection (ACD).
Transverse image reconstruction	Iterative methods or filtered backprojection.	Iterative methods or filtered backprojection.
Radionuclides	Any emitting x rays, gamma rays, or annihilation photons. Optimal performance for photon energies of 100–200 keV.	Positron emitters only.
Spatial resolution	Depends upon collimator and camera orbit. Within a transaxial image, the resolution in the radial direction is relatively uniform, but the tangential resolution is degraded toward the center. Typically about 10 mm FWHM at center for a 30 cm diameter orbit and ^{99m}Tc. Larger camera orbits produce worse resolution.	Relatively constant across transaxial image, best at center. Typically 4.5–5 mm FWHM at center.
Attenuation	Attenuation less severe. Radioactive attenuation correction sources or x-ray CT can correct for attenuation.	Attenuation more severe. Radioactive attenuation correction sources or x-ray CT can correct for attenuation.

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PET-MRI



Disadvantages with PET-CT

a. High dose
b. Sequential (no simultaneous acquistion)

Advantages with PET-MR

a. No extra dose
b. Soft tissue imaging
c. Functional imaging

Main problem with PET-MR: Photomultiplier tubes in the PET are sensitive to magnetic fields

Solution:

a. Two scanners in series
b. Integration of PET-hardware into the MRI-gantry

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PET-MRI



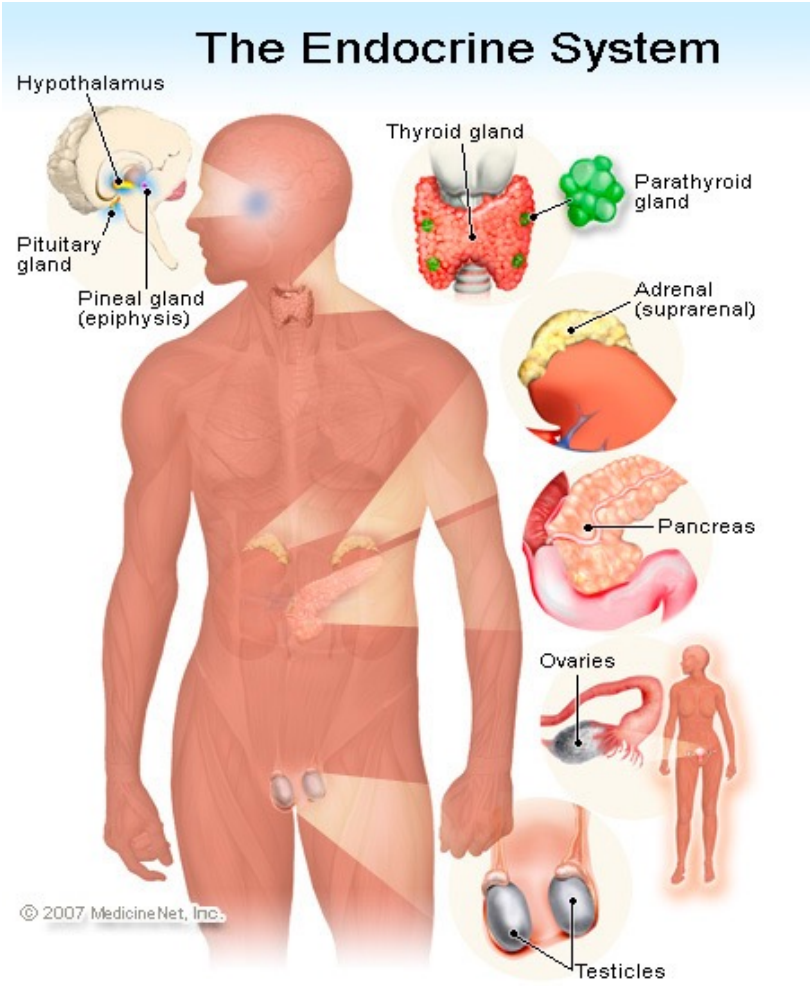
This technology has been available since 2011 (Siemens Biograph mMR), why has it not succeded yet?

a. No attenuation correction, difficult to calculate attenuation coefficients
b. Long time scans compared to PET-CT due to long MR-sequences
c. Expensive
d. Need MRI-compatible detectors instead of photomultipliertubes, more complicated, costly maintenance

Case 15



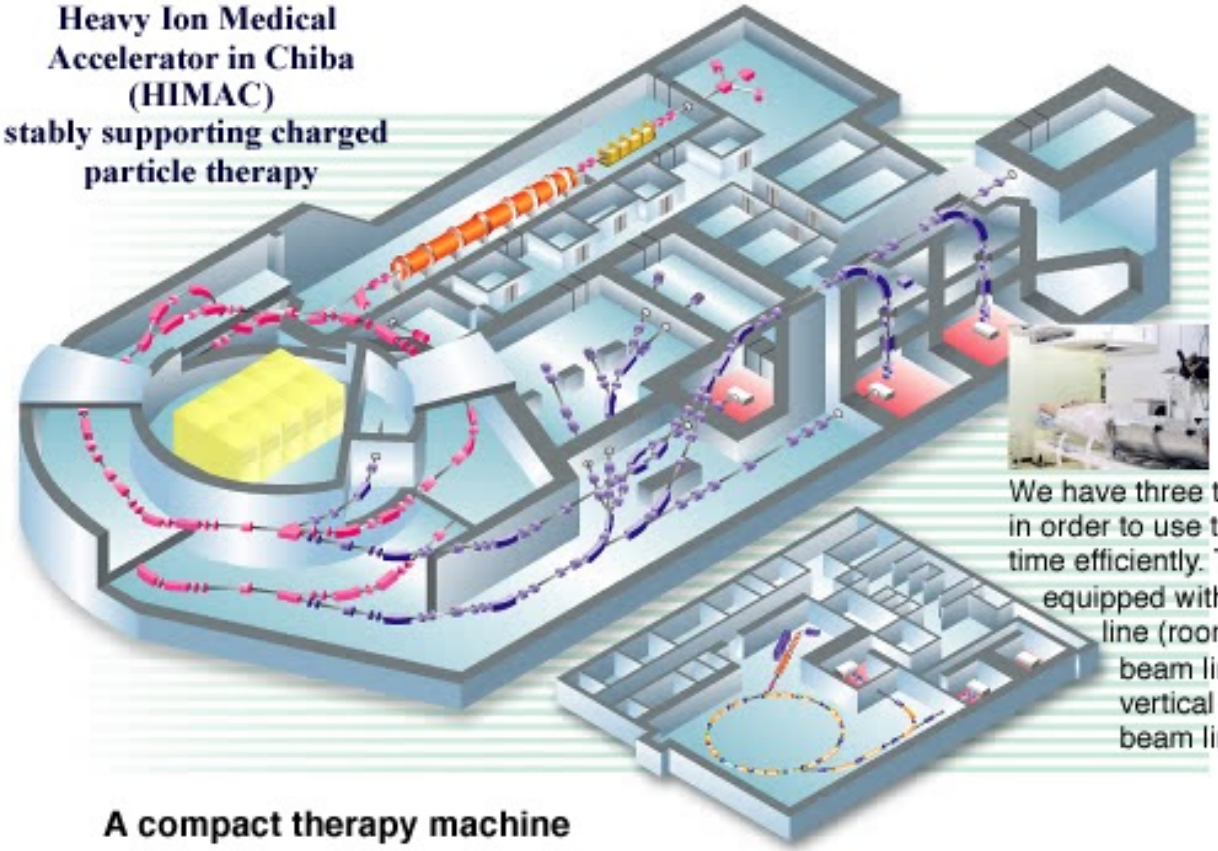
- The PET-scan shows a primary tumor in the right adrenal gland. A biopsy of the tumor shows the type, and several blood tests are performed that supports the original theory. There is also a secondary intracranial tumor that is so difficult to reach that a proton-therapy is required to remove the tumor properly without harming the surrounding tissue.



Nuclear therapy

Non-invasive surgery

Heavy Ion Medical Accelerator in Chiba (HIMAC) stably supporting charged particle therapy



We have three treatment rooms in order to use the HIMAC beam time efficiently. These rooms are equipped with a vertical beam line (room A), a horizontal beam line (room C) and vertical and horizontal beam lines (room B).

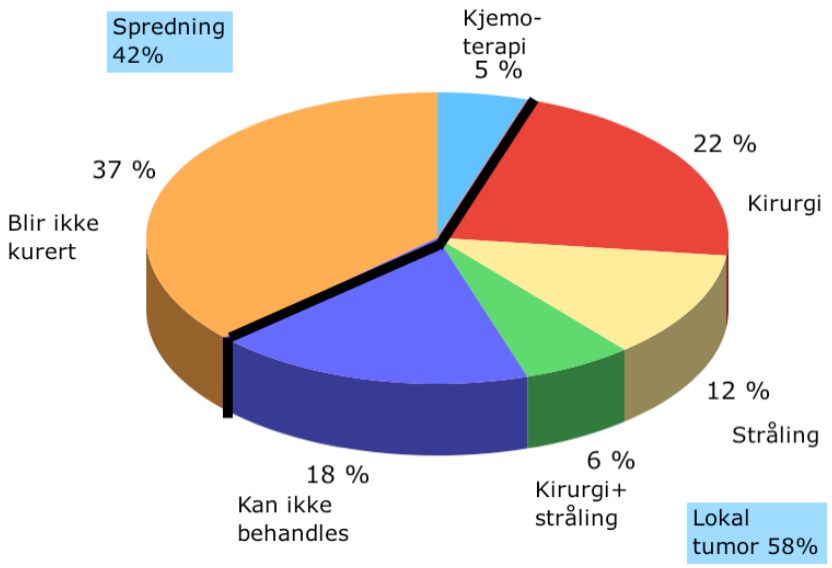
A compact therapy machine

The NIRS completed research and development on a compact carbon therapy machine in FY 2005. Gunma University has adopted our proposal and will start construction of a new therapy facility in FY 2006. The NIRS is giving technical support to this project at Gunma University.

Kilde: NIRS, Chiba, Japan

Non-invasive surgery

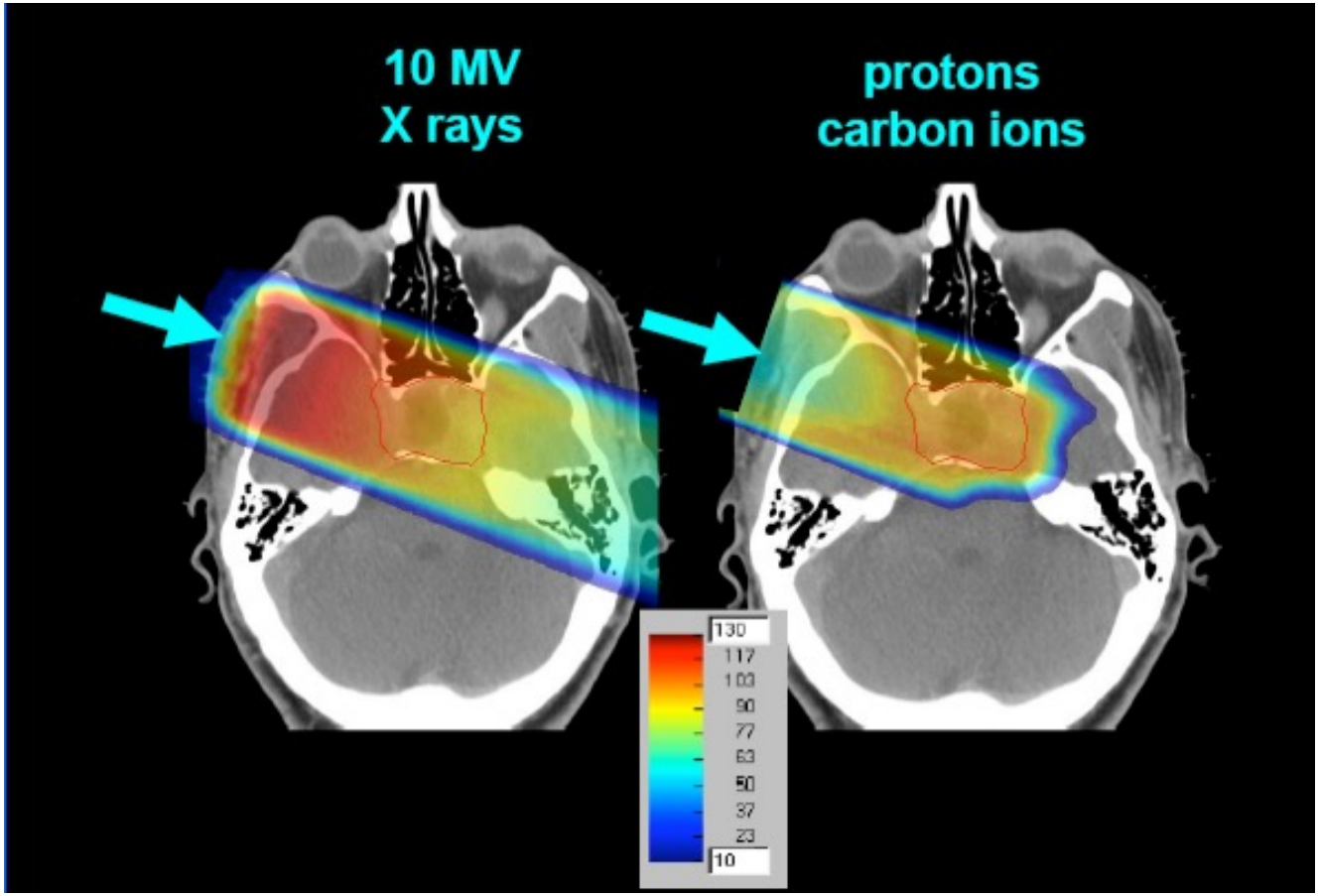
A treatment for patients with a local tumor not possible to treat with regular therapeutic methods



Kilde: Magne Guttormsen, Fysisk Institutt, UIO

Non-invasive surgery

Better dose distribution to the tumor



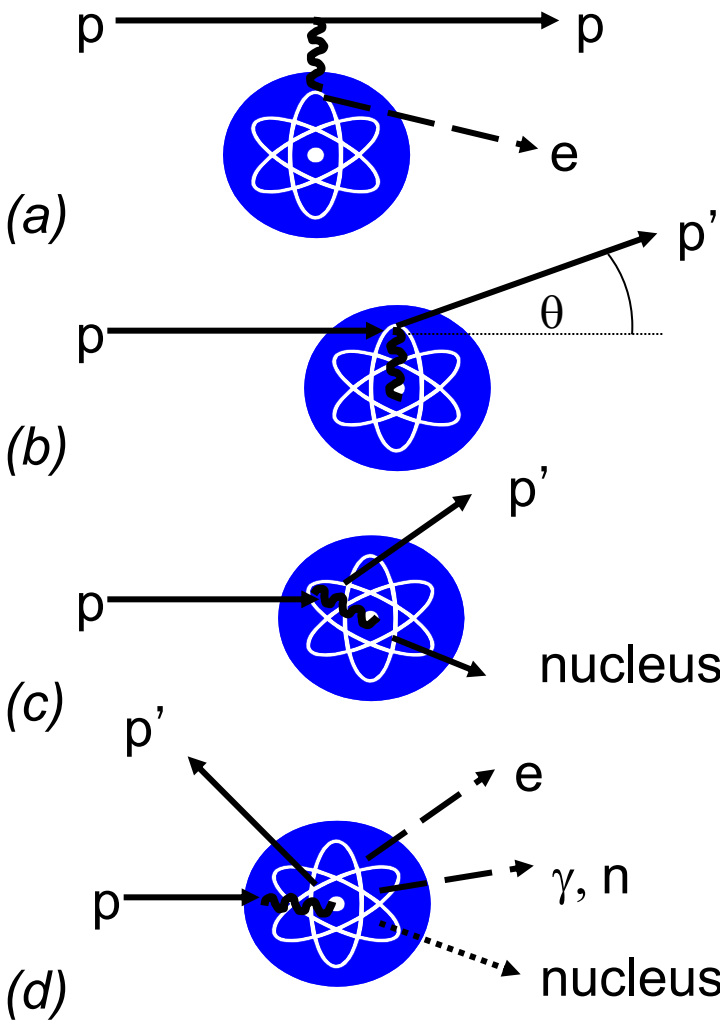
Source: Magne Guttormsen, Fysisk Institutt, UIO

Proton therapy

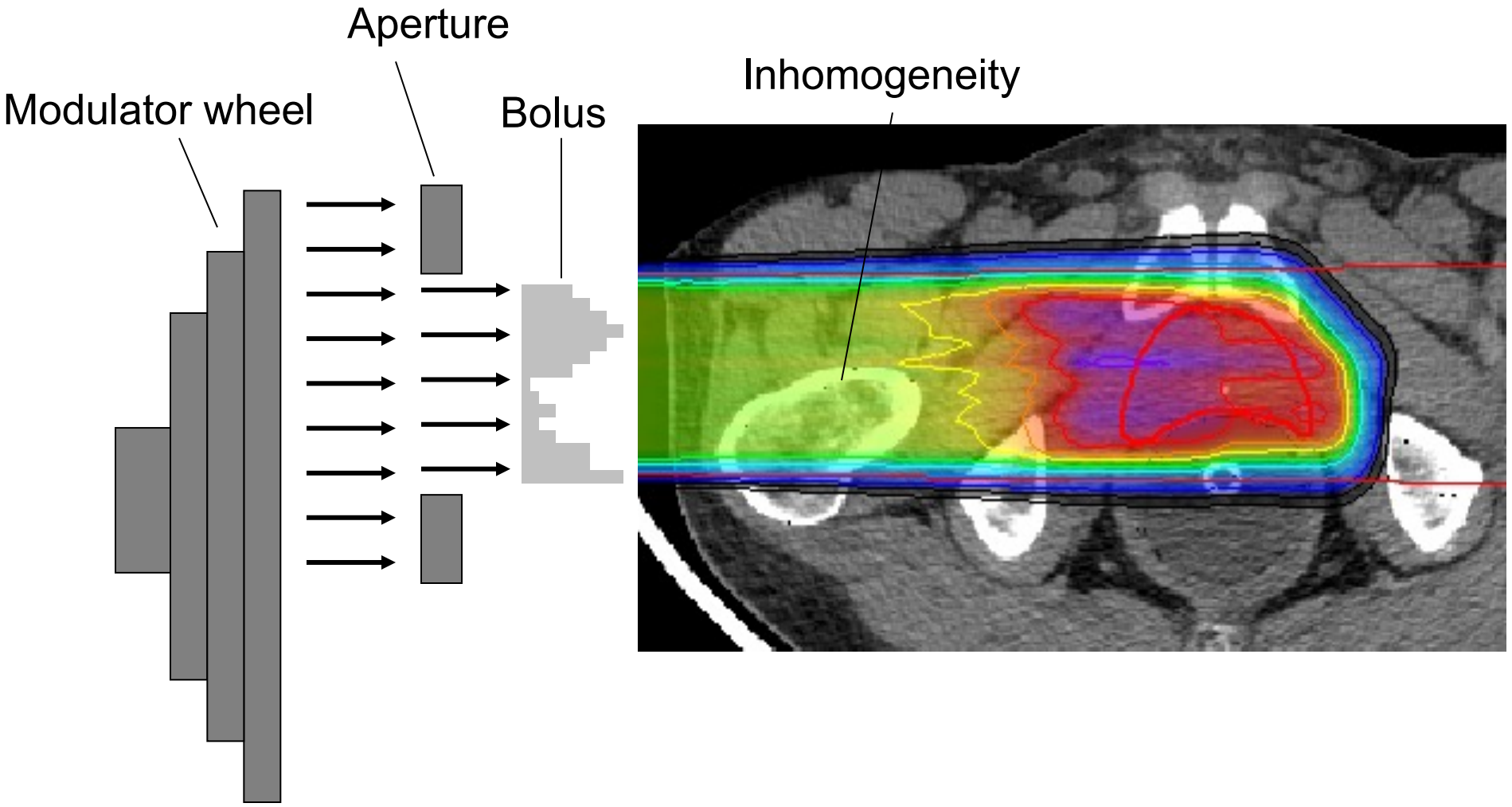


Proton interactions

- Electron interactions (*a*)
  - Ionization
  - Excitation
- Nuclear interactions (*b-d*)
  - Multiple Coulomb scattering (*b*), small q
  - Elastic nuclear collision (*c*), large q
  - Nonelastic nuclear interaction (*d*)



Proton Beam design



- Reinhard W. Schulte, Loma Linda University Medical Center

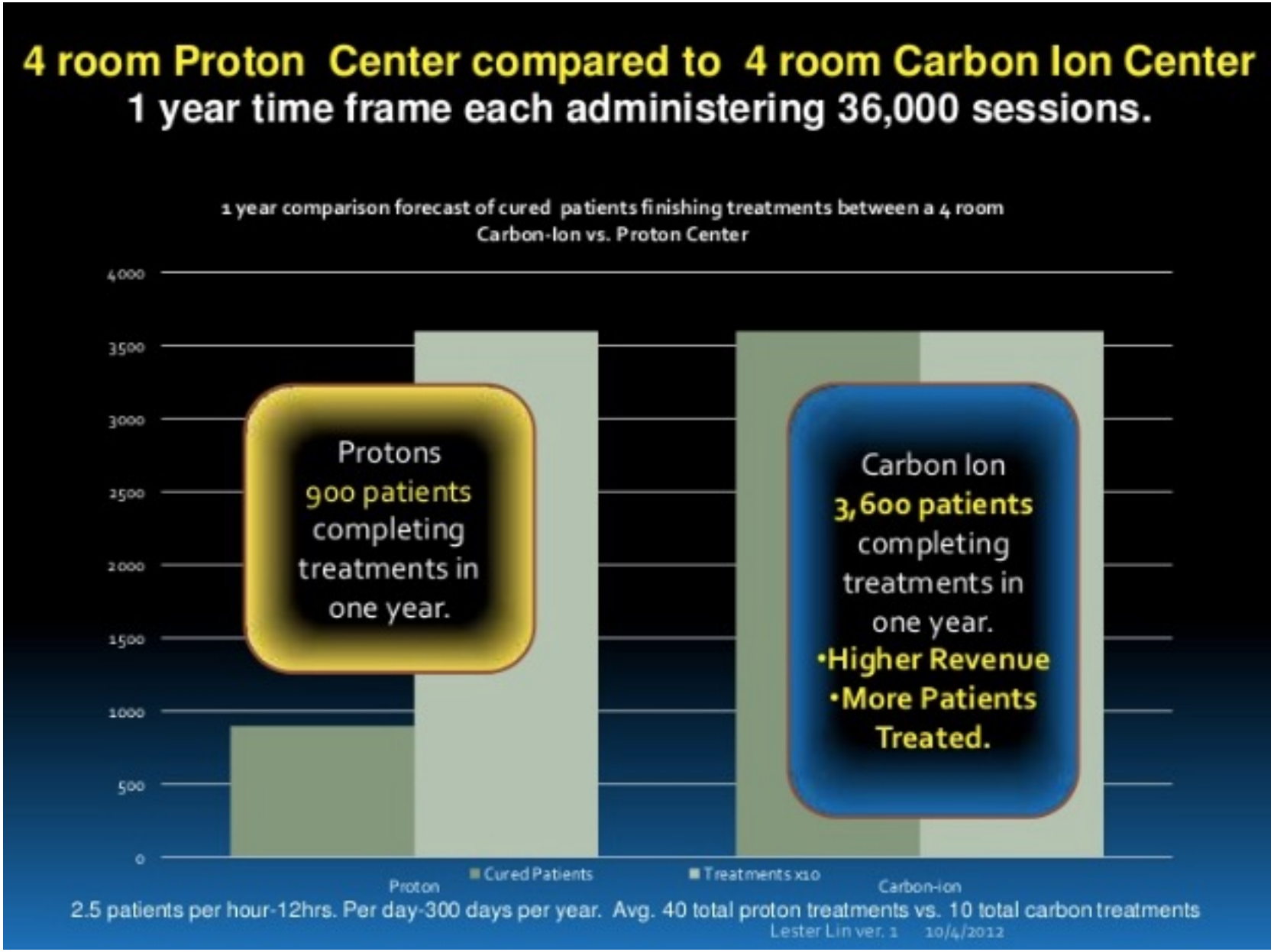
Proton Beam shaping device





Wax bolus Cerrobend aperture Modulating wheels

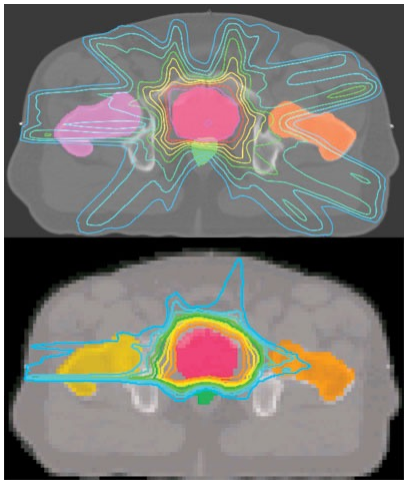
- Reinhard W. Schulte, Loma Linda University Medical Center



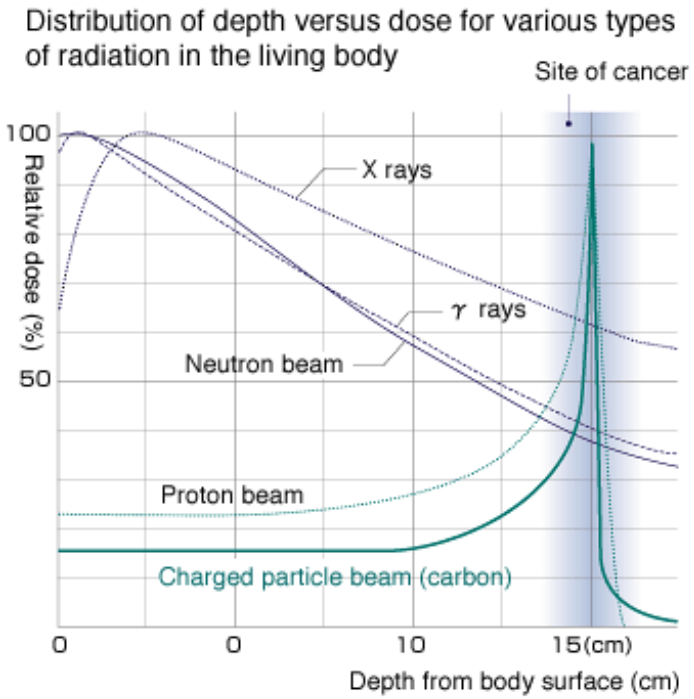
Bragg peak systems Inc

Non-invasive surgery

Heavy ion therapy (Proton-terapi)



http://www.nature.com/nature/journal/v449/n7159/box/449133a_BX1.html



Kilde: NIRS, Chiba, Japan



http://www.triumf.info/public/about/virtual_tour.php?section=3&single=18

The ionization density (number of ions per unit of path length) produced by a fast charged particle along its track increases as the particle slows down. It eventually reaches a maximum called the Bragg peak close to the end of its trajectory. After that, the ionization density dwindles quickly to insignificance. In fact, the ionization density follows closely the LET

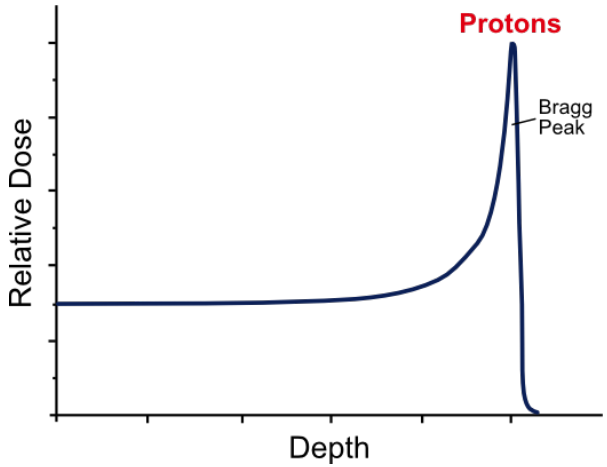
The Bragg Peak

- A moving particle will loose energy according to the Bethe-Bloch formula

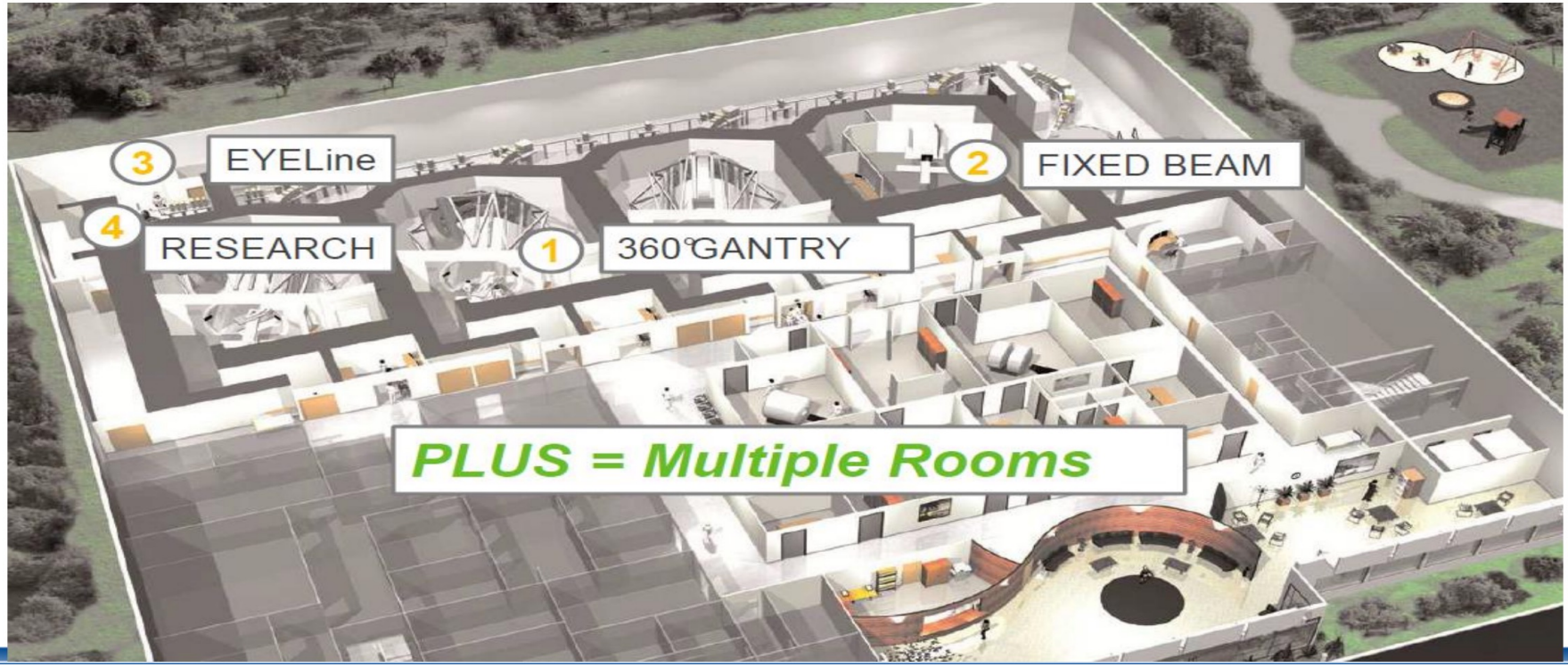
$$-\frac{\mathrm{d}E}{\mathrm{d}x} = \frac{4\pi n z^2}{m_e c^2 \beta^2} \cdot \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1-\beta^2)}\right) - \beta^2\right]$$

due to collisions with electrons of the absorber material. In addition there is a nuclear fragmentation reaction that gives very complex alterations of the particle field composition

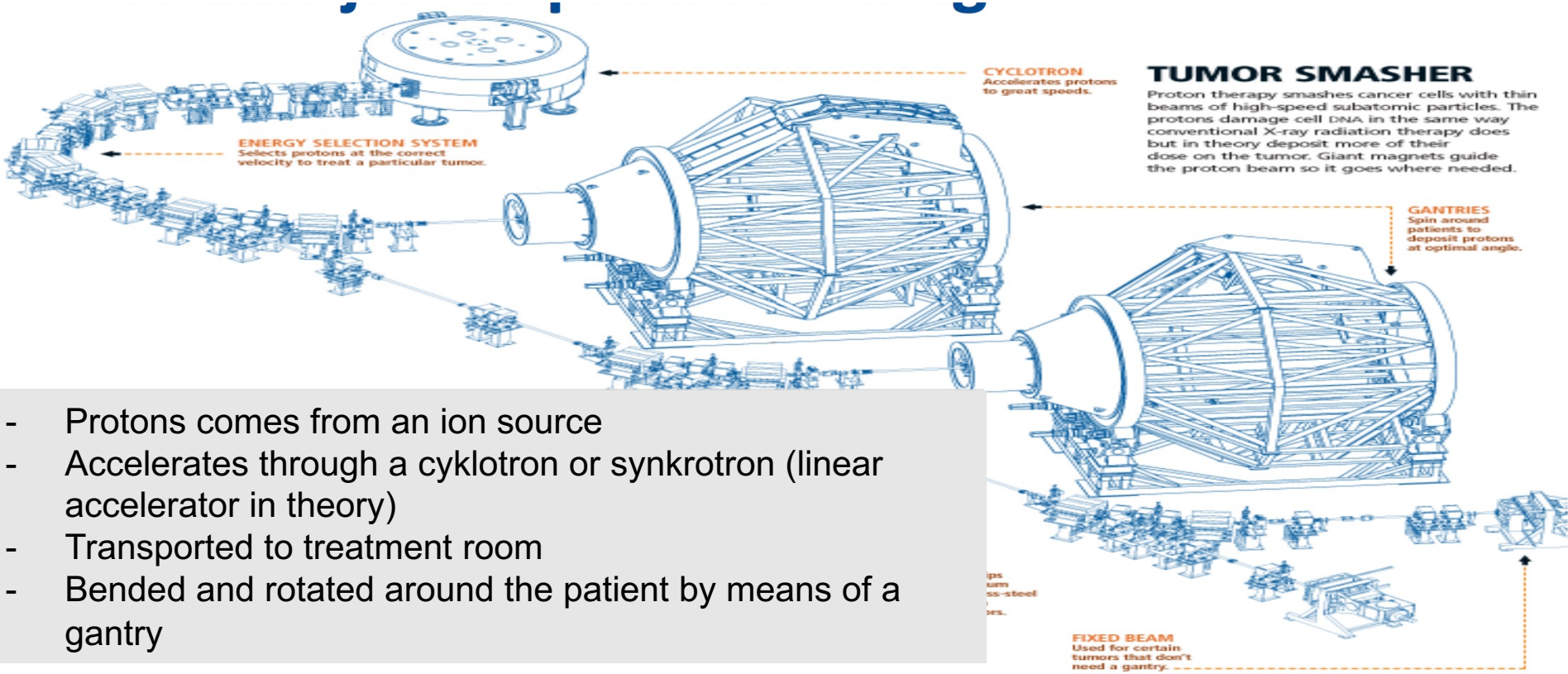
- As energy decreases, the statistical probability of more nuclear interactions increase dramatically, and most of the energy is deposited shortly before the kinetic energy reach zero



A typical proton center

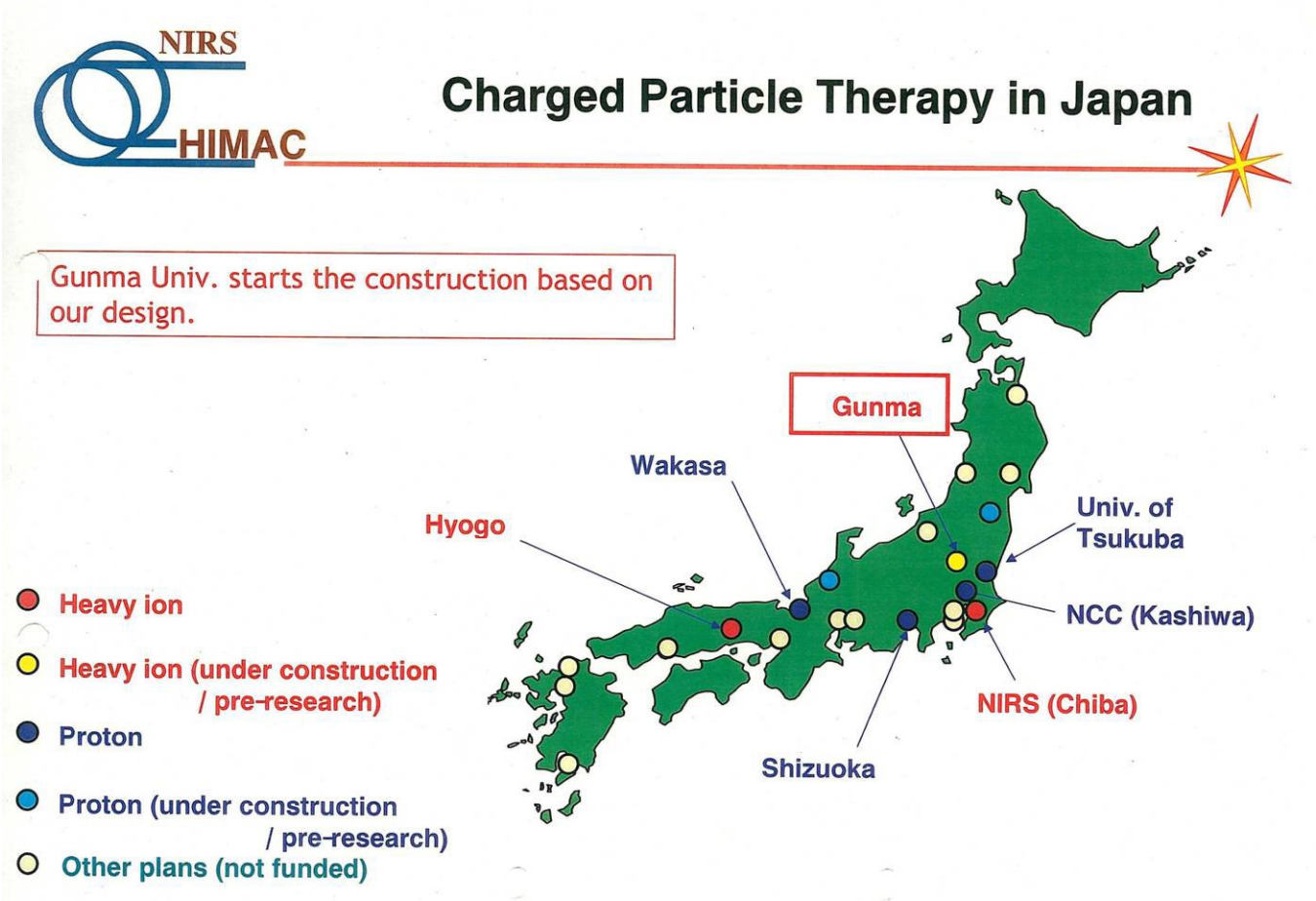


The gantry



- Protons comes from an ion source
- Accelerates through a cyklotron or synkrotron (linear accelerator in theory)
- Transported to treatment room
- Bended and rotated around the patient by means of a gantry

Non-invasive surgery



Kilde: NIRS, Chiba, Japan

Non-invasive surgery

Minimalized heavy ion therapy centre Tung-kjerne terapi sentre

- Less size than today's centres, protons only
- A part of Radiumhospitalet, will open in 2024
- Reduced investmentcost, approximately 1,9 billion NOK



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Proton therapy in Oslo



Proton therapy in Oslo



Non-invasive surgery



Case 15



- The tumors are finally removed, and the patient recovers quickly. After two more days, the patient is discharged from hospital, but he will never return to his old, stressful occupation as a stockbroker. A more thoroughly biopsy of the removed tumor from the adrenal gland confirms the already accepted theory and explains the apparent heart infarction

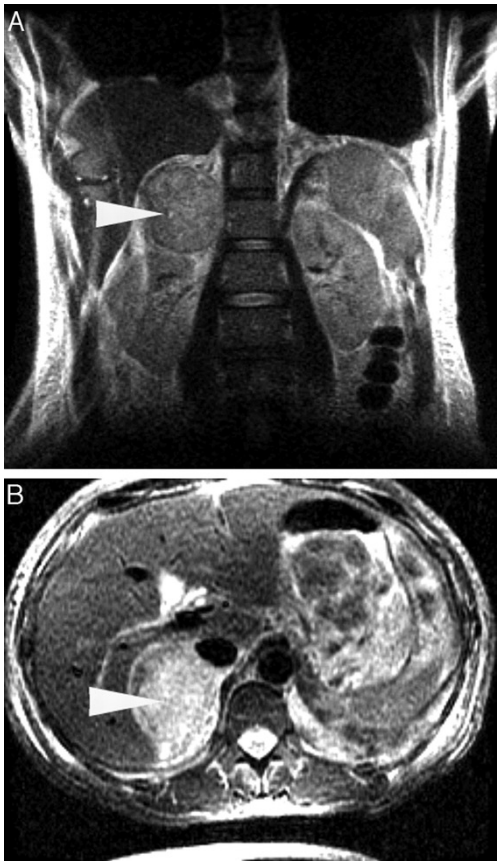
What is the connection between the tumor and the heart attack?

Case 15



- Answer: Pheochromocytoma. A hormone-producing tumor, often located in the adrenal glands. When producing adrenalin, the heart is so stressed that the increased myocardial oxygen demand in the heart will lead to a myocardial damage.

- When the adrenaline-levels fall, the heart rhythm will be stabilized, and no signs of the cause will be evident. These tumors have nothing to do with the previous lung cancer tumors.



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