Characteristics of X-rays

Hatem Said, Simone Platzke

How to use this handout?

This handout is part of the AO Trauma Course for ORP. The left column is the information as it may be given during the lecture. The column on the right gives you space to make personal notes.

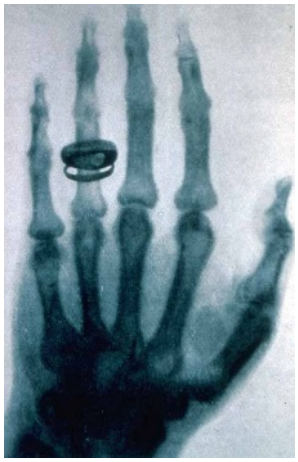
Learning outcomes

At the end of this lecture you will be able to:

- Explain what x-rays are
- Discuss the difference between x-rays and Image Intensifier (II)
- Describe correct positioning of the II
- Explain how to protect well against radiation

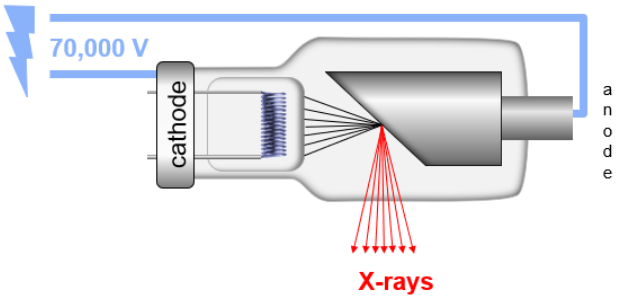
History

Wilhelm Röntgen, Professor of Physics in Würzburg, Bavaria, was the first person to discover the possibility of using electromagnetic radiation to create what we now know as the x-ray. Röntgen referred to the radiation as "X", to indicate that it was an unknown type of radiation.
The first x-ray that Röntgen ever created is an image of his wife's left hand (incl. wedding ring).
The Nobel Prize in Physics 1901 was awarded to Wilhelm Conrad Röntgen "in recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him".



1. What is an x-ray?

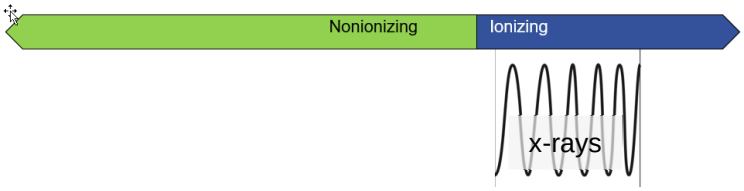
X-rays are a form of invisible, high frequency electromagnetic radiation. The wavelength of x-rays is very small/short, energetic and with great penetrating power. They are produced by accelerating electrons at a metal target in a special tube (cathode) and received by the anode. Some of this energy is turned into X-radiation.



X-ray waves

There is:

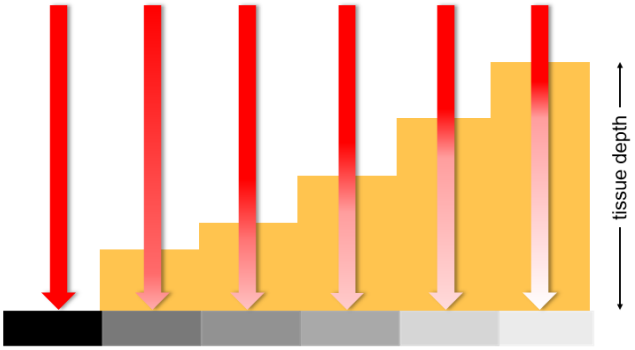
- Nonionizing radiation, such as microwaves, radio waves, ultraviolet, infrared, laser and ultrasound.
- Ionizing radiation (capable of producing ions) such as α-rays, β-rays, γ-rays, and x-rays.



X-rays in medical application

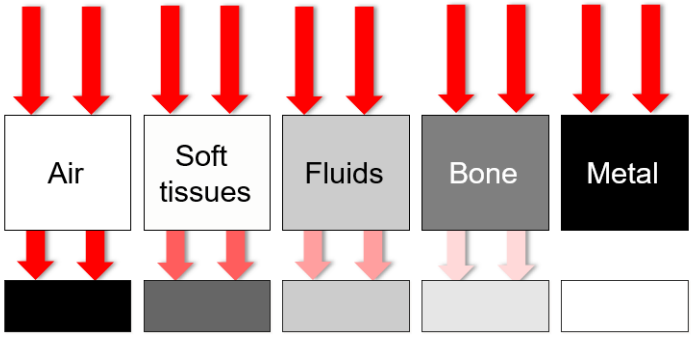
X-ray image density depends on the tissue volume through which the rays pass.

- More x-rays will penetrate when less tissue volume. The projection on the film will be darker.
- Less x-rays will penetrate when more tissue volume. The projection on the film will be lighter.

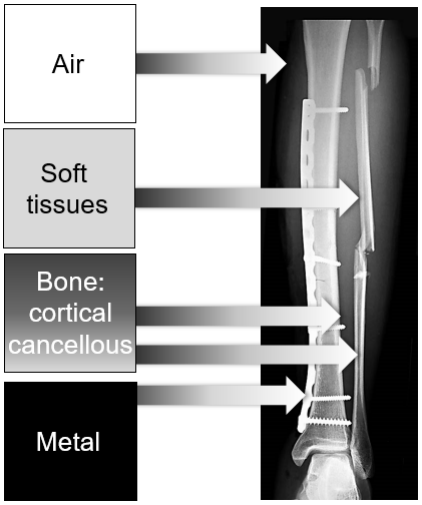


Also the type (density) of the tissue, or material, will play a role.

- Air (with lower density) will be projected black on the film, as more radiation penetrates.
- Metal, which has a higher density, will be projected white, as more radiation will be blocked.
- Bone will be projected grey. Also, the difference between the densities of cortical and cancellous bone can be seen on the film, since cortical bone has a higher density than cancellous bone.

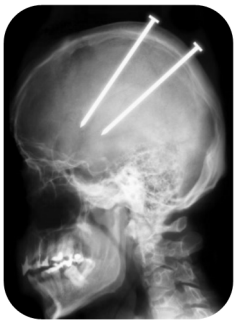


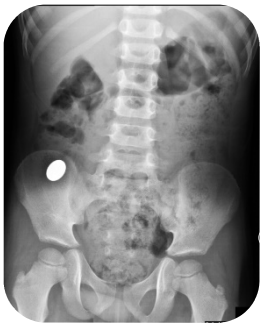
Example: projection in open tibia fracture



Radiopaque and radiolucent

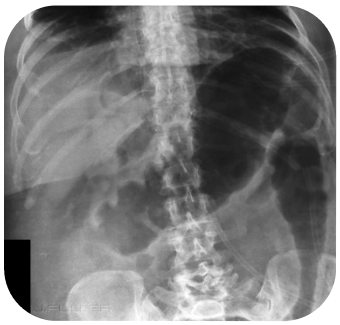
Radiopaque objects block radiation. They are opaque to radiation.





On the left is an image of a child who swallowed a metal coin. It will be visible on an x-ray because it is radiopaque and blocks the rays. The location of the coin can easily be identified.

Radiolucent objects do not block radiation. For example, if a child swallows a plastic toy coin (radiolucent) it will not be visible on an X-ray film as the rays passed through it.



Intestinal gas is radiolucent and patterns of intestinal gas can lead to differential diagnoses.

Physical facts

Units of measurement

The energy produced by x-radiation is measured in Rems.

Grey is the unit that represents the energy deposited in material (1 Gy=1 Joule/kg).

The energy deposited in biological material is expressed as a dose equivalent, called a Sievert and it reflects the biological effect of radiation (1Sv=1 Joule/kg).

The three units are related and are used depending on the location of its measurement.

Rem		Energy delivered by x radiation
Gray	1 Gy=1 Joule/kg	Energy deposit in material Reflects the physical effect
Sievert	1 Sv=1 Joule/kg	Reflects the biological effect

100 rem = 1 Gy = 1 Sv

100 millirem = 1 mGy = 1 mSv (=1000 μSv)

Natural radiation

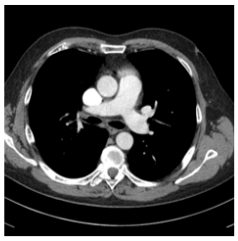
Everyone is exposed to a natural background radiation to a greater or lesser extent.
Examples of normal exposure are:

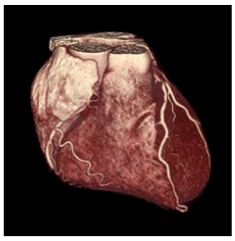
- Cosmic rays during high altitude flights (ranges from 0.001 to 0.01 mSv/hour)
- Natural background radiation that we receive daily (0.01 mSv/day)

Radiation in medicine
The most important radiation exposure for patients usually takes place in the radiology department:

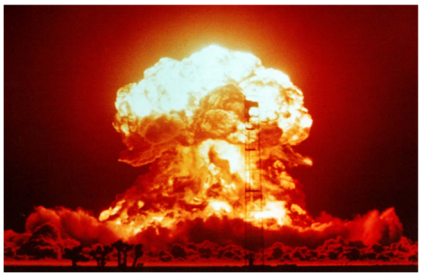
- A chest x-ray is 0.1 milli-Sievert
- A CT scan of the head is 1.5 milli-Sieverts
- A CT of the entire body is 9.9 milli-Sieverts
- A cardiac CT angiogram is 6.7–13 milli-Sieverts

Type of scan	Radiation exposure in milli-Sievert
Chest x-ray	0.1 mSv
CT scan head	1.5 mSv
CT whole body	9.9 mSv
Cardiac CT angiogram	6.7–13 mSv





Accidental exposure (radiation)
The dose of radiation required to produce radiation sickness is between 500 and 1000 mSv, which is equal to the amount to which the citizens of Hiroshima were exposed in 1945.

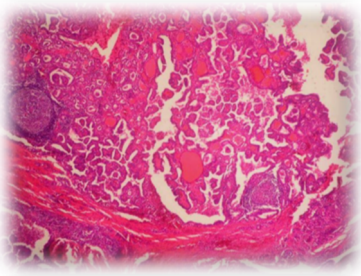


Biological facts

Somatic effects
If an individual receives a dose greatly in excess of the threshold dose, the effects will occur in a relatively short period after the radiation (early effects radiation sickness from 500–1000 mSv). Late somatic effects include leukaemia, thyroid cancer or radiation cataracts.
However, if the dose is not greatly in excess of the threshold dose, many of the resulting effects will be of a temporary nature and reversion to normal conditions usually occurs.

Stochastic (random) effects
Stochastic (random) effects of radiation are different. There is no safe threshold and damage is cumulative with multiple exposures to radiation. The late effects of this are thyroid cancer or leukemia.
Such effects may not manifest themselves until many years after the radiation exposure, e.g., survivors of the atomic bombs in Hiroshima and Nagasaki.

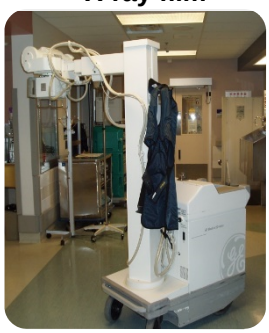
Regarding thyroid cancer, 85% of papillary carcinoma of the thyroid are radiation induced. From literature is known that the carcinogenic dose of radiation to induce thyroid carcinoma is 100 mili-Sieverts.



The threshold value per year which should not be exceeded by surgeons, staff or patients is 300 milli-Sieverts for the thyroid gland, 150 milli-Sieverts for the eye, and 500 milli-Sieverts for the hand.

Image intensifier and x-ray film

X-ray film



Also portable X-ray equipment can be used in the OR.

Image intensifier

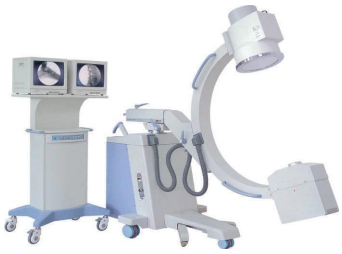
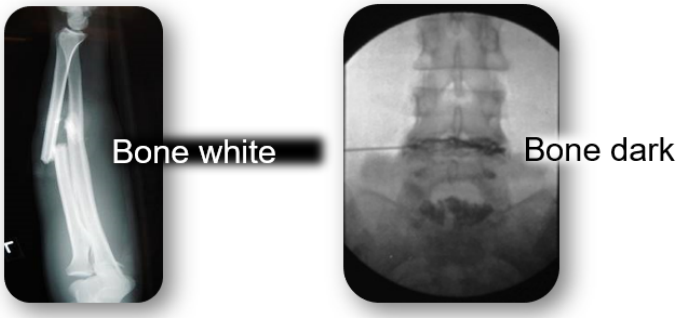


Image intensifier is a direct visual procedure, using a screen, monitor and x-ray tube. It will be used in most orthopaedic fracture cases (IM Nails, ORIF).



Absorption and scatter

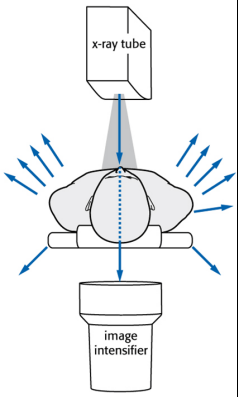
≈ 80% absorbed by patient

≈ 10–20% scattered

≈ 2% transmitted to the image intensifier

The radiation not absorbed by the patient is scattered. This scattered radiation can affect the team and surgeon.

In this example, the x-ray tube is emitting ionizing radiation, which is either reflected or absorbed by the patient. Just a fraction of the x-rays pass through the patient to the image intensifier.



Radiation scatter is mainly directed back towards the source, the x-ray tube.

For every thousand photons reaching the patient, 100–200 photons are scattered. Just 20 reach the image detector and the rest are absorbed by the patient. This is the radiation dose.

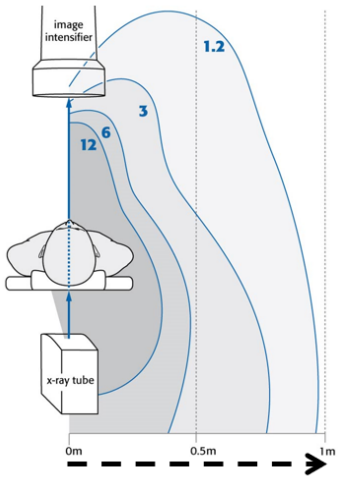
Scattered radiation from the patient is the main source of radiation for the surgical team!

Dose rate around C-arm

Distance
If you measure the dose rate around a mobile C-arm you have scattered radiation. The further away from the patient, the lower is the dose of scattered radiation.

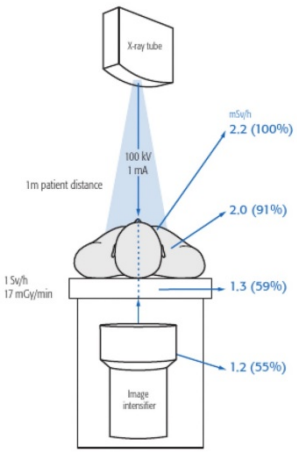
If you stand further than 1 metre away, there would be less, or no radiation.
It is, therefore, very important to ensure that you stand at a safe distance from the patient, image intensifier and x-ray tube.

Inverse Square Law: Radiation decreases very rapidly with increasing distance from the source. Example: hold a flashlight a few centimetres from a white wall in a dark room and see the narrow beam of light hitting the wall. Then walk away from the wall with the flashlight still pointing on the wall and note how the beam of light gets wider and less intense as you move back.

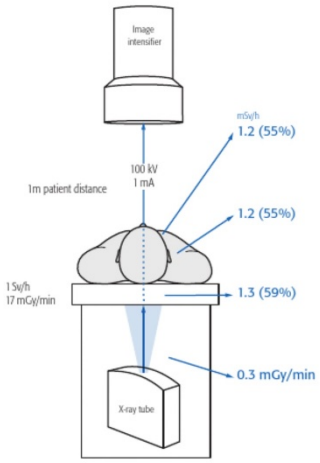


So always keep at a safe distance of the image intensifier and the x-ray tube.

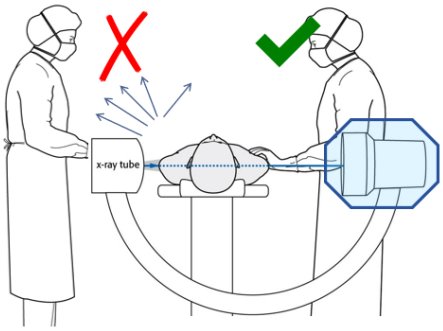
Position of the tube
It is important to know the effect of the x-ray tube positions. When the x-ray tube is above the patient at 1 metre distance, your eyes receive a dose of 2.2 milli-Sieverts per hour. Wear thyroid shields and eye protection to reduce high neck and facial exposure.



When the C-arm is inverted and the x-ray tube is below the patient, you will be exposed to just 55% of the scattered radiation. Therefore, the x-ray tube position is of paramount importance. As a rule, you should notice that positioning the x-ray tube below the OR table reduces high dose rates to the eyes. The best configuration during surgery is with the intensifier above and the x-ray tube below. This will reduce the radiation dose to the team and the surgeon's eyes by 3 times or more.



If the surgeon stands on the x-ray tube side, thyroid exposure is 3 to 4 times higher than standing on the intensifier side.



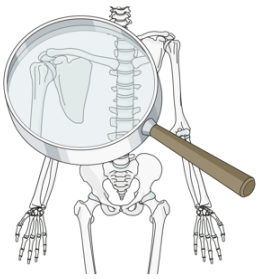
The dose rates to the torso from the x-ray tube side are 0.53 milli-Sieverts per minute, whereas on the intensifier side it is just 0.02 milli-Sieverts per minute.

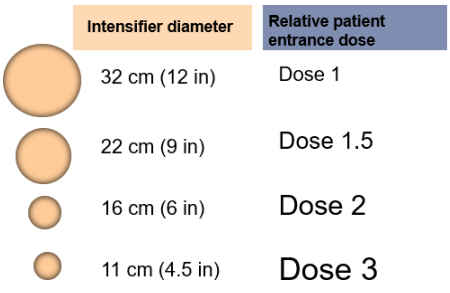
Standing on the intensifier side reduces the amount of general radiation exposure to one tenth. When the surgeon performs a locking procedure he/she should stand close to the intensifier and ensure that the x-ray tube is not close to the hands.

Diameter

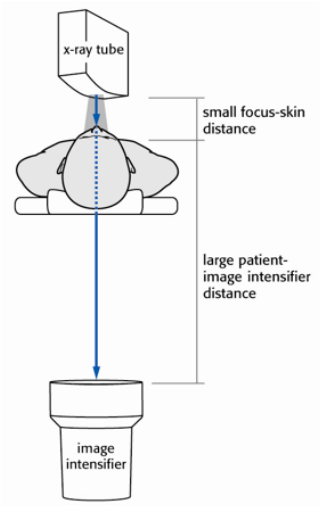
Another factor which increases scattered radiation to surgeons is the diameter of the intensifier. The more you want to magnify your image the higher the relative patient entrance dose has to be.

Do not use too much magnification because you will then have to increase your patient entrance dose and will, as a result, increase scattered radiation risk.





Also important to know is that the patient dose will increase if the distance between the focus and the skin is short and the distance between the patient and the image intensifier is long.



The scatter is reduced by placing the patient close to the image intensifier and further away from the x-ray tube.

Protection—ALARA principle

ALARA: As Low As Reasonably Achievable

The primary goals of radiation safety are to avoid any unnecessary radiation exposure and to keep all exposure As Low As is Reasonably Achievable . Three main ways to keep your doses ALARA: **time**, **distance**, and **shielding**.

Take Home-message

It is important to repeat that the exposure can be reduced by

1. Not entering the room when not necessary
2. Considering the position and orientation of the C-arm
3. Reducing the exposure to scatter radiation
4. Wearing personal protective equipment
5. Keeping distance
6. Keeping the hands out of the beam

Summary

You should now be able to

- List different implant materials used in traumatology
- Discuss implant properties
- Explain the use of specific materials for specific cases

Reflect on your own practice:

Which content of this lecture will you transfer into your practice?

How can you improve your current practice?