PRINCIPLES OF IMAGING METHODS FOR MEDICAL STUDENTS

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KAROLINUM

Principles of Imaging Methods for Medical Students

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CONTENTS

PREFACE

Dear students,

Welcome to the first edition of "Principles of Imaging Methods for Medical Students". In this textbook you can find all what you need for passing the Imaging Methods exam. Moreover, we hope that the text will help you in your future general medical practice. The textbook brings basics of imaging methods techniques, guidelines for their indications and also their contraindications. We believe that the text will help you in understanding and in decision making process which procedure will be the best for your future patients who suffer from specific symptoms.

Let me express my thanks to all the co-authors, my colleagues from the Radiology Department, Third Faculty of Medicine, Charles University in Prague. All of them are experienced radiologists and great teachers who care about medical students' education. They worked hard and prepared each chapter with great care. My thanks belong to Dr. Aaron Rulseh as well. He spent a lot of time on English editing and we highly appreciate his help.

Finally, let me wish you all the best in your medical study. If you study successfully, it will be our great pleasure and the best reward!

Hana Malíková

1 BASICS OF GENERAL RADIOLOGY

First, we would like to mention general rules applicable to all radiology, which all physicians should be aware of and follow them.

General rules for X-ray examinations not only in the Czech Republic:

- All imaging examinations using X-rays may be performed only for proper medical indications (Czech law 202/2017). Only medical doctors can request X-ray examinations.
- An X-ray (plain film, CT, angiography, etc.) requisition must be written/printed and signed by a physician. The exam specification (what kind of imaging?), justification (why is it necessary?) and important clinical data must be stated in the written request.
- All relevant clinical information must be considered by the indicating physician to prevent unnecessary radiation exposure.
- Every instance of radiation exposure must be affirmed by an application expert, i.e., a radiologist or radiographer (able to approve plain X-ray examinations in subjects older than 3 years of age). They are also responsible for assessing the reasonability of the requested test.
- Pregnancy is the only relative contraindication of X-ray examinations, there is no absolute contraindication.

Consider the following questions before creating a requisition for any X-ray examination:

- Is it necessary? Will the patient outcome, treatment, follow-up schedule, etc., be affected by the result of the requested exam?
- Can another test be used instead? Especially consider tests without radiation.
- Is the timing of the examination appropriate?
- Did I provide all relevant information to the radiologist?
- Do you have any doubts? Consult your radiologist!

1.1 X-RAYS

X-ray creation, attributes and radiation protection

X-rays, X-radiation or Roentgen radiation/rays are terms used for electromagnetic radiation of wavelengths 10^{-8}–10^{-12} m. X-rays are created when fast moving electrons collide with metal atoms and their energy is transformed to electromagnetic radiation. The following imaging methods use X-rays: radiography, fluoroscopy, computed tomography (CT), digital subtraction angiography (DSA), hybrid imaging methods such as PET/CT or SPECT/CT and bone mineral densitometry.

X-ray creation

X-rays are produced in an X-ray tube (Fig. 1.1), a special type of a vacuum tube. The main parts of an X-ray tube are the **cathode (negatively charged)** with a filament, and an **anode (positively charged)**. The heated cathode filament emits electrons. The function of the positive anode is to attract the negatively charged electrons, which are produced by the filament of the cathode. The higher the electrical potential between the cathode and the anode, the stronger this "attraction" of electrons (i.e., current) will be. The magnitude of this electrical potential, i.e., difference between the anode and cathode, is regulated by adjusting the (kilo) voltage (kV). During the application of high voltage across the tube, the electrons impact (collide with) the angled anode and the following occurs:
- Great amounts of heat are produced (99% of electron energy is transformed into heat).
- X-rays of varying wavelengths are produced when the rapidly travelling electrons decelerate as they impact with the anode (approximately 1% of the energy is transformed into X-rays).

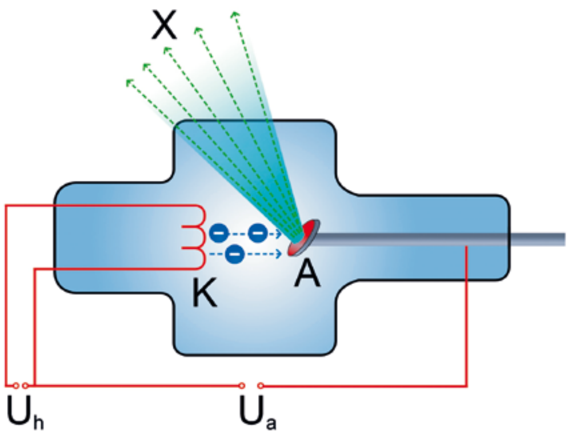

Fig. 1.1 Schema of an X-ray tube. An X-ray tube consists of the negatively charged cathode and the positively charged anode. The heated cathode filament emits electrons. The positive anode attracts the negatively charged electrons. X-rays are generated as a result of a collision of the highly speedy traveling electrons with the atoms of the anode. (K – cathode; A – anode; U_a – source of electric power for anode; U_h – cathode heating current; X – X-rays)

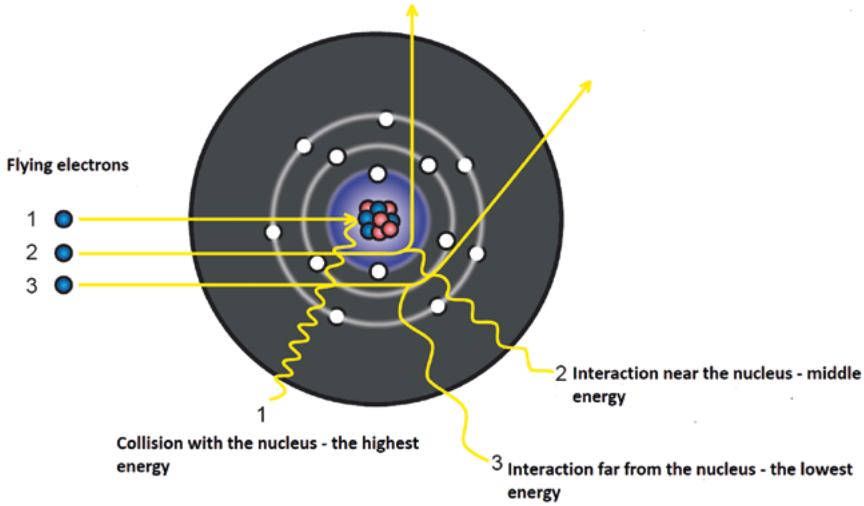

Fig. 1.2 Principle of bremsstrahlung radiation. Bremsstrahlung radiation is produced by high-energy electrons bombarding the target. When bombarding electrons penetrate into the target, some electrons travel close to the nucleus due to the attraction of its positive charge and are subsequently influenced by its electric field. The course of these electrons would be deflected, and a portion or all of their kinetic energy would be lost. The "lost" energy is emitted as X-ray photons, specifically braking radiation.

To be able to function properly for long periods of time (a long "tube life"), the anode must be able to withstand heat. Therefore, the material which is used in the construction of the anode is usually a block of copper, which is able to dissipate the heat; additional material used in the construction of the anode is usually a tungsten plate. Tungsten is used as it has a high melting point, allowing the anode to withstand very high temperatures when electrons strike it and X-rays are produced. The other materials which are used for anode construction are tungsten-rhenium and molybdenum. X-ray photons produced in the anode are of two types: **bremsstrahlung (braking radiation) and characteristic**.

Bremsstrahlung (from German "bremsen" – to brake and "Strahlung" – radiation, i.e., "braking radiation" or "deceleration radiation"; Fig. 1.2) **is produced by electron and tungsten nucleus interaction**. The electron path is deflected and it is decelerated by the positively-charged nucleus. It loses kinetic energy, which is converted into radiation (an X-ray photon). Electrons traveling close to the nucleus undergo much more deceleration than electrons traveling farther away. Therefore, the emitted X-ray photons differ in their energies; **bremsstrahlung has a continuous spectrum**. The highest energy photon is created when the electron directly hits the tungsten nucleus. The radiation wavelength (which is inversely proportional to the energy of the emitted photons) depends on the speed of electrons hitting the anode, which is proportionate to the tube voltage. The higher the tube voltage, the greater the speed (kinetic energy) of electrons colliding with the anode and therefore the higher the energy of the X-ray beam. Thus, increasing tube (anode) voltage shifts the X-ray spectrum to the right, towards higher energy and shorter wavelengths.

Characteristic radiation (Fig. 1.3) is produced when an electron collides with an electron in the inner electron shell of an anode atom and ejects the electron from the shell. As

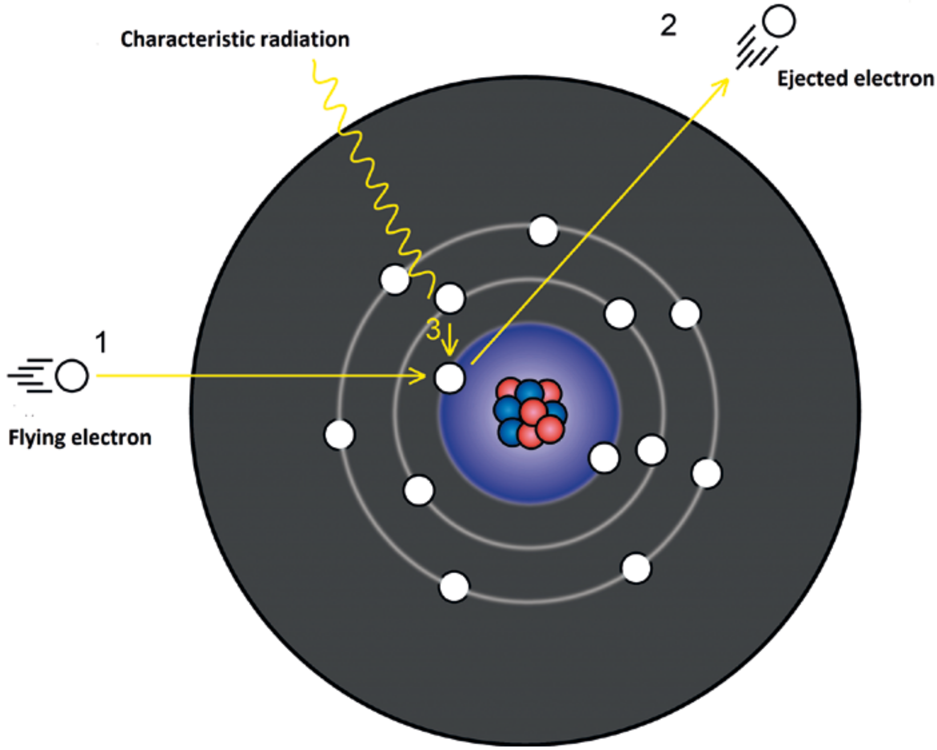

Fig. 1.3 Principle of characteristic radiation. This energy emission happens when the fast-moving electron collides with the shell electron, the electron is ejected leaving behind a "hole". The outer shell electron fills this hole with an emission of the single X-ray photon (characteristic photon), with the energy level equivalent to the energy level difference between the outer and inner shell electron involved in the transition.

a result, an electron from the outer shell then fills the vacancy and an X-ray photon of a particular frequency (wavelength) is emitted. The energy (frequency) of the X-ray photon equals the difference between the energy states of the electron shells. Therefore, characteristic X-ray photons are produced at a few discrete frequencies, sometimes referred to as spectral lines, which depend on the target (anode) element used, and are thus called **characteristic lines**.

X-ray properties and interaction with matter

Penetration: X-ray photons penetrate objects; the greater the energy that they possess (harder X-ray), the greater the penetration.

Absorption of X-rays in an object depends on the object thickness/density and its elemental composition. **The higher the proton number of the element, the greater the absorption.** Bones contain a lot of calcium; therefore, they have high X-ray absorption. On the contrary, there is only minimal absorption in the lungs.

Photochemical effect: a chemical reaction that results in film blackening.