THIEME FLEXIBOOKS

Roentgenologic Anatomy

An Introduction

W. Frik · U. Goering

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Translated by L. G. Rigler · P. Spiegler

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Preface to the English Edition

For quite some time before the second German edition of this book appeared in 1975, many of our colleagues had suggested we should publish it in other languages as well. In fact, we found that our little compendium of roentgenologic anatomy had assumed importance in helping many paramedical and technical aides of the radiologist in their work.
We were, therefore, most grateful to Dr. Günther Hauff for having decided to publish an English language edition of this introduction to the field of roentgenologic anatomy. Professor Leo Rigler and Dr. P. Spiegler performed a consistently outstanding translation job. One of us was fortunate in having had an opportunity to discuss the book personally and exhaustively with Professor Rigler two years ago, so that every detail of the translation is in fact congenial and on the same plane of inspiration as the original text.
It is indeed sad that Professor Rigler did not live to see the publication of the Englisch language edition, and that our designer, Mr. K. Hofmann (Erlangen, Germany), too, died before the book came out of the press. This English edition is, therefore, dedicated to the memory of these two gentlemen without whose unstinting efforts and creative drive its publication would not have been possible.
The English edition is chiefly a translation of the second German edition, the roentgenotechnical chapters of which had already been tailored to represent the present state of knowledge. Another step in this direction was taken during the preparatory and streamlining work that went into the English translation. The description of the organ system was also improved upon, with further details filled in. The same is true of the description of the examination methods and the chapter on contrast medium studies.
It goes without saying that there can be no absolute perfection. Hence, we should welcome an equally stimulating response from readers as experienced by us on publication of the first and second German edition.

Aachen and Erlangen, February 1980

W. Frik
U. Goering

Preface to the First German Edition

The circle of those who work together with the radiologist as aides or advisors has steadily increased with time. These include, on the one hand, x-ray technicians, administrative assistants and unskilled helpers. On the other hand, there are the physicists and engineers who help the physician satisfy his desire for perfect x-ray equipment, the manufacturers' technical or sales representatives, and the technicians who service it. Common to all these groups of people is the need to feel their way into the intellectual world of the physician. The training they receive and the amount of medical knowledge they need to do their respective jobs differ greatly. However, in each case, basic anatomical knowledge is certainly the most necessary fundamental information required to understand the various medical applications of x-rays.

This book attempts to present the minimum amount of knowledge of this subject required by the radiologist's aide who looks after the x-ray installation. It deals mainly with normal anatomy, touches on physiology only when it is essential to the understanding of anatomy, and, on this basis, offers a description of radiological examination procedures. Special attention has been given to the nomenclature and definition of the important technical terms.

A few disease concepts are mentioned, though only when they help the layman acquire a deeper understanding of the physician's world.

Some of the professional groups addressed by us will find a need to extend their knowledge beyond what is presented. Numerous works dealing specifically with anatomy and radiology are available and it is not our intention to replace them with this book. We consider our task as fulfilled if we have helped those interested in a limited amount of knowledge, if we have presented it in a practical, useful form and if, for those who need a broader knowledge, we have made the introduction to specialized studies easier.

Our project was stimulated by the friendly reception according to a series of lectures on the same subject given by Professor Dr. A. Gebauer of Frankfurt am Main in 1952. They were given as a course for x-ray engineers and technicians of the Siemens-Reiniger Company, Erlangen. In April 1955 we published an *Introduction to Radiological Anatomy* for the company's internal use. The enthusiastic reception of the book and the many confirmations of its practical usefulness have encouraged us to publish a new edition for a wider audience.

We are very grateful to the publisher, Dr. B. Hauff and his son, Mr. G. Hauff, for kindly acceding to our wishes and for many suggestions. The drawings came from the pen of Mr. K. Hofmann. The specialized character of our book could not have been realized without his insight.

Erlangen, July 1959 W. Frik U. Goering

Contents

Medical Terminology

Medical terminology derives predominantly from Latin, which was the language of the sciences until the last century, and to some extent from Greek. Latin and Greek terminologies have been retained to this day for reasons of tradition and for the sake of international communication.

Latin continues to be used for the official international terminology for anatomical detail in the human body. Additionally, however, an anatomical vernacular has developed in many languages. Its make-up and content deviate to some extent from the international terminology. Other medical words (for example, body functions, diseases and disease symptoms) are generally assimilated into the living language while retaining Latin and Greek word elements. These include, for example, the following concepts of practical importance.

Anatomy means "the art of dissection". This word, which, like the other technical terms below, originated from the Greek, now characterizes the science of the form and construction of the human body. In European civilizations, anatomy was first practiced as a science by the Greeks. Later it was adopted by the Romans.

Physiology is the study of the normal life functions inside the body. It should not be confused with *psychology,* which is the study of mental processes (psyche = mind, soul, psychic = relating to the psyche). The study of changes and occurrences inside the body due to disease is known as *pathology* (diseased = pathologic).

Literally translated, the word *diagnosis* means "decision". In medicine it is used to characterize the recognition and naming of a disease.

The doctor arrives at the diagnosis on the basis of the *anamnesis* (= memory, i.e., early history of the disease), the *symptoms* (= disease indicators), and the results of various investigation methods, among which belongs the radiological examination. The word *therapy* is used to describe the treatment of the disease (literally: nursing).

As a result of new knowledge medical terminology has also undergone changes from time to time. This holds for anatomical and also for clinicomedical terms. In anatomy, the Paris nomenclature *(Nomina Anatomica)* is currently recommended ("NA 1955", 4th Ed. International Anatomical Nomenclature Committee 1977) (nomenclature = system of terms). In this book, however, only anglicized terminology is used.

Radiation Physics and X-ray Technology

X-rays

X-rays, like visible light, are a form of electromagnetic radiation. They differ from visible light in their substantially shorter wave length and their ability to penetrate solid substances. X-rays are classified as ionizing rays because they have the ability to ionize air. The group of ionizing rays also includes a number of other types of radiation which produce similar biological effects.

The discovery of x-rays by Wilhelm Conrad Roentgen on November 8, 1895, gave the physician a noninvasive technique for looking inside the human body in order to recognize early skeletal and organ changes caused by disease (diagnostic radiology). The rapidly ensuing awareness that x-rays also have a biological effect on the human body ushered in the use of x-rays and other ionizing radiations in the treatment of disease (radiation therapy).

The biological effect must also be considered in diagnostic radiology. It influences the type and scope of the x-ray examination and necessitates the observation of radiation safety regulations that have been adopted internationally (see p. 91).

To produce x-rays one needs an x-ray machine with an x-ray tube ("x-ray generator" and "x-ray radiator"). Basically, the generator, a high voltage transformer with associated rectification and the requisite switches and regulating devices, energizes the x-ray radiator, i.e., the x-ray tube inserted in a protective housing, with a high-voltage direct current. The x-rays are produced inside the x-ray tube and radiated from a source approximating a dot and known as the focal spot. The dial selectors on the control console enable the tube potential (kV) to be regulated, thus making it possible to select the penetrability, radiation quality or "hardness", as well as tube current (mA) upon which the radiation intensity depends. A timer is used to control the exposure (s). Alternatively one may encounter combined selection of time and tube current (selection of the mA · s product). Modern x-ray generators come equipped with automatic exposure timers which measure the radiation dose ahead of the recording system (for example, the film screen combination), and which automatically terminate the high voltage potential (exposure) after a specified dose has been achieved. New installations also have controls which automatically regulate the dose rate in fluoroscopy. The production and properties of x-rays are extensively discussed in textbooks on radiographic technique. The study thereof is indispensable for paramedical personnel involved with x-radiation.

The radiological examination of patients is performed with x-ray apparatus especially adapted for the positioning of sick people and which are capable of producing an x-ray image. They are consequently equipped with fluoroscopic screens or image-intensified fluoroscopy or TV-monitored fluoroscopy; they are also equipped with an x-ray tube stand, tube container and cassette holder.

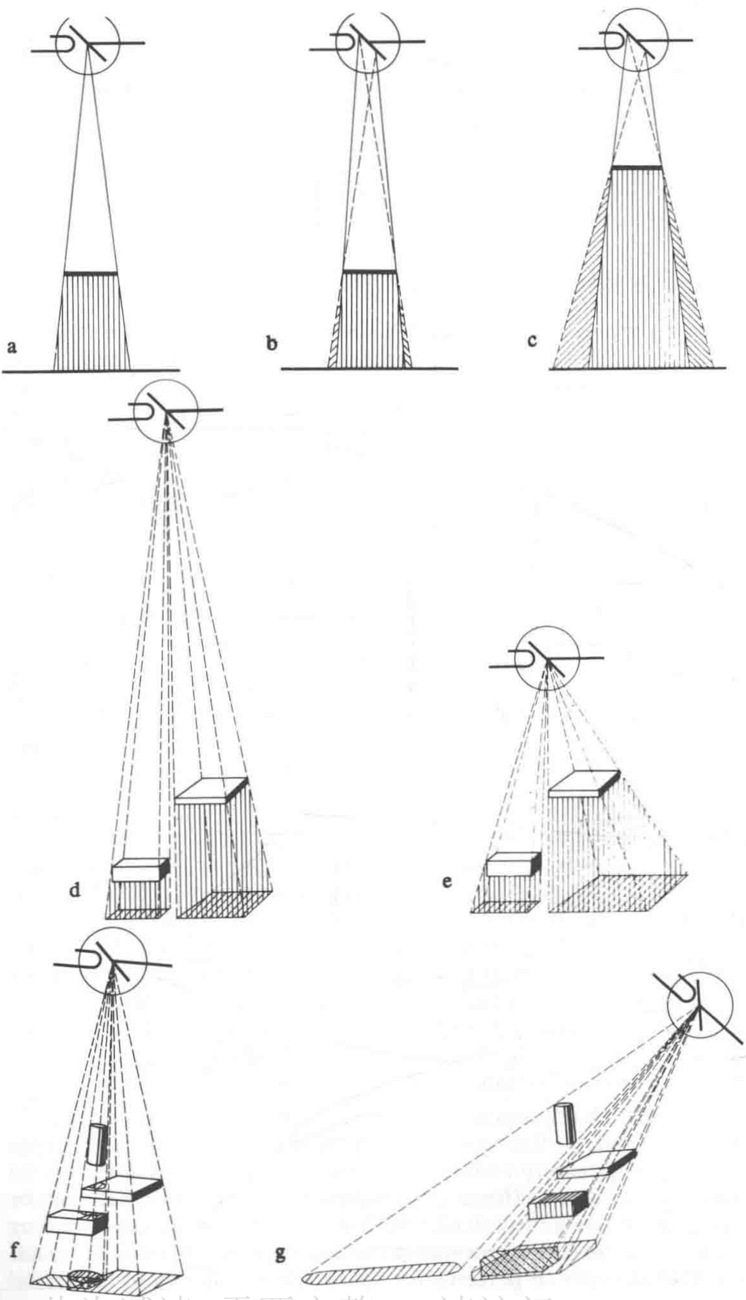
The Radiograph (Roentgenogram)

In the x-ray examination, one must constantly remind oneself that the making of x-ray images is governed by laws that differ from those governing visible-light photography. Photographs are reflected images; the surface facing the camera is imaged. The shape of the object is not just perceived from the outline of the object, but also from the various degrees of brightness of the light reflected by its surface. The spatial arrangement of the various objects is not only perceived from their relative sizes but also from their relative overlappings.

During the making of an x-ray image, x-radiation is passed through the body. The density variations (contrast) in the radiograph result from differences in x-ray attenuation in the object (dependent on thickness, density and chemical composition). The x-ray image is thus equivalent to a shadow image of a body with various degrees of transparency. The differences in the x-ray intensity of the beam produced by its passage through the object are transformed beyond the object into a visible-light image by means of a fluorescent screen and into optical density differences by means of radiographic film.

The size of the radiation source (focal spot size), the relative distances between the tube, the object and the film, as well as the angle of incidence of the radiation, dictate the geometric size ratios on the radiograph. Distortions cannot be avoided, especially when the object in the pathway of the x-rays is of significant size. Such magnifications can, however, be kept within tolerable limits by selecting a sufficiently large distance between the focal spot and the film (distance from focal spot to film plane). At times, due to varying ratios of density and contrast, the image appears to be three-dimensional, but this is of course an optical illusion.

The radiograph is a summation of stacked images and does not contain information about the depth dimensions of the object. A single exposure can only convey limited knowledge about the three-dimensional nature of the object. This is also valid for the physician even though he can imagine anatomical detail and has years of experience in reading radiographs. Several exposures of the object in different directions are essential in order to perceive the spatial shape. Mainly for historical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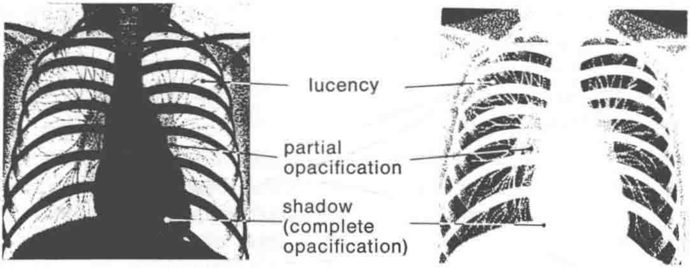

Fig. 2 Differences between fluoroscopic image and radiograph. The terms for brightness of the image are based on the fluoroscopic image.

reasons, terms such as "shadow", "shadowing" or "lucency" are used when describing radiographs. These terms derive from the language of fluoroscopy. The radiograph is the negative of a fluoroscopic image. The physician therefore calls an illuminated area on the film a "shadow" or a "density" and an area of higher optical density a "lucency".

For the purpose of interpretation the radiograph is rotated until it is in the same position as the fluoroscopic image, i.e., the impression arises that the patient is standing in front of the observer. When describing a radiograph, "left" refers to the left side of the patient (right side of the observer) and "right" refers to the right side of the patient (left side of the observer).

Radiography and Fluoroscopy

In diagnostic radiology one differentiates between fluoroscopy and radiography.

Fluoroscopy permits real-time observation of the object. It allows motion studies. By continuously changing the fluoroscopic viewing direction the object can be studied three dimensionally.

Radiographs are used for diagnosis as well as for documentation of radiographic findings. In contrast to fluoroscopy, the individual exposures "freeze" the object at a momentaneous phase of movement. For

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Fig. 1 Effect of various factors on the radiographic image.
Effect due to focal spot size and relationship of distances.
Superimposition of various objects using a central beam contrasted with the effect of an oblique projection of the x-ray beam.

imaging very small details or those with poor contrast, radiography is superior to fluoroscopy. X-ray exposures of the skeleton and to some extent of internal organs are taken as overall views in standard positions. Exposure techniques, although not the subject of specific agreements, are relatively uniform internationally.

With the help of combined radiographic and fluoroscopic equipment it is possible to expose "spot films" during fluoroscopy and to record the object in a desired projection at a desired phase of movement. This applies especially in the case of those inner organs which cannot be radiographed satisfactorily by conventional techniques.

General views and spot films can further be complemented by special procedures.

Films exposed between intensifying screens are generally used in the making of radiographs. As is the case with photographic film, the sensitive layer of the film consists of a silver bromide emulsion. The radiation has a small direct effect but the film is predominantly exposed by blue light emitted by the intensifying screens. In special procedures (e.g., mammography), special films are used without intensifying screens. These films are more sensitive to x-rays and are also capable of recording fine detail; however, they require more radiation than screen-film combinations. The invisible radiation behind the object produces in the sensitive layer of the film an invisible image, known as the latent image. It is transformed into a visible image in the developing solution and into a fixed image by immersion in the fixing solution.

Xeroradiography offers yet another possibility of recording anatomical detail. In this process, the radiation image is not recorded on film but as a latent electrostatic image on a uniformly charged photoconductive layer. The latent electrostatic image is then made visible by dusting with a fine powder. The dust image is then transferred and fixed on paper.

In contrast to the radiographic image on film, the characteristics of the image in xeroradiography are completely different. Edges are enhanced while contrast over large areas is leveled out. In xeroradiographic imaging, the magnitude of the radiation contrast is not the decisive factor, but rather the contrast gradient at the location in question, i.e., the steepness of the transition region relative to its surroundings. This can be of advantage in imaging small details which are poor in contrast. As a result, xeroradiography has found application in a number of procedures such as soft tissue diagnosis, mammography, angiography, and the demonstration of air-filled organs (for example, the larynx). Tomographic and serial exposures can also be made with this process (see below).

Photofluorography (the small photograph of the fluoroscopic image) has made cost-reduced radiography possible. It is mainly used in mass screening.

By means of body section radiography (planigraphy, tomography, stratigraphy, zonography) it is possible to image individual organs or organ parts free of overlapping by other organs. The x-ray tube and the film or the patient move simultaneously in opposite directions during the exposure and only one layer of the body is sharply imaged. Objects which lie outside the plane of the section are blurred out. Simultaneous exposures of several layers can also be performed. Various kinds of motion may be used when performing tomography, depending on the purpose of the examination. The motion may be linear, cyclic and polycyclic, hypocyclic or ellipsoid and duospiral or trispiral.

Objects may be studied three-dimensionally by means of stereoradiography. This procedure can also be used to measure the depth of the object within the part examined, independent of its position with respect to the recording plane. To achieve this, two exposures of the same object are taken at slightly different angles of the x-ray beam. The images are then evaluated with optical instruments.

A rapid film-changing technique is used to study organs in motion or rapid changes in the size or position of an organ, such as motion of the heart or filling and emptying of blood vessels. It is accomplished by means of an automatically controlled exposure series, most often at a frequency of 1 to 6 exposures per second.

X-ray kymography and related techniques made it possible to record slow movement of certain organs but such techniques are now obsolete and have been replaced by cinefluorography and electronic methods.

The introduction of electrooptical image intensifiers has led to completely new fluoroscopic and recording procedures. The exit image on the image intensifier is 1000 to more than 10,000 times brighter than that of the conventional fluoroscopic screen. In modern fluoroscopy the exit image on the intensifier is now recorded, as a rule, by a television camera and then transmitted to one or several TV monitors. Dark adaptation by the radiologist is no longer necessary.

In image intensifier television fluoroscopy, the monitors can be placed anywhere with respect to the fluoroscopic equipment. The image can be viewed at a freely chosen location and stored on magnetic tape.

The fluoroscopic procedure can be reviewed by replay of the magnetic tape with no additional radiation exposure to the patient. Detail enhancement in certain areas of the image is made possible by means of electronic manipulation of the signal. In certain cases direct radiographic exposures can be replaced by single and series photography of the intensifier's exit screen (known as indirect exposures) by means of a 70 or 100 mm camera.

Cinematography of the image intensifier has made higher image frequencies possible without unduly high exposure of the patient to radiation. Detailed evaluation of rapid motion processes, for example, of the heart and blood vessels, is thus possible.

For certain surgical procedures, such as nailing a bone, or endoscopic procedures (e.g., examination of the stomach or intestines by means of an endoscope), fluoroscopy and recording techniques are used not for diagnostic purposes but to orient and position the instruments.

Computer tomography is a new method of radiographic visualization of body sections. With this procedure radiographs are not obtained in the usual manner or in conventional projections. Rather, the patient's body is scanned, perpendicular to its longitudinal axis, either by an x-ray beam collimated to a few millimeters in diameter or by a fan-shaped beam of x-rays.

Radiation detectors measure the transmitted radiation behind the patient. The x-ray tube and the radiation detector move along a circle perpendicular to the patient's longitudinal axis during the recording procedure. Some systems consist of a stationary ring of detectors.

The imaged volume is a "slice" a few millimeters thick. It is irradiated axially from many directions. During the recording phase several hundred thousand attenuation measurements are made by the radiation detectors. They are processed in a computer to yield a matrix presentation of the attenuation distribution, which is displayed on a monitor or oscilloscope screen.

The image shows the attenuation differences in the layer in different shades of gray or color. The resolution in computer tomography is poorer than in conventional radiography. However, differences in x-ray attenuation of less than 1% can be detected and measured.

Computer tomography already plays an important role in examinations of the skull and especially of the brain. New and important diagnostic information concerning organs in the chest and in the abdominal cavity is also being obtained by means of computer tomography.

The following summary abstracts the more important fluoroscopic and radiographic procedures.

A. Fluoroscopy

1. Conventional fluoroscopy.
2. Image intensifier fluoroscopy.
   The minified image on the exit screen of the image intensifier is viewed directly by means of magnifying optics.
   Neither method is common any longer.

3. Image intensifier television fluoroscopy (IITF).
   The image on the exit screen of the image intensifier is recorded by a TV camera and transmitted to one or more monitors.

B. Single and Serial Exposures

1. Direct radiography.
   The exposure is recorded on x-ray film sandwiched in a cassette between two intensifying screens or on special nonscreen film. The film may be replaced by special equipment for recording an electrostatic image (xeroradiography).
2. Indirect radiography.
   a) X-ray photography of image intensifier;
      Photography of the exit screen of an image intensifier on a special 70 or 100 mm film by means of a special camera;
   b) Photography of a television monitor;
      Photography of the image on the monitor screen (see A3) by means of a special camera;
   c) X-ray photography of a fluorescent screen (photofluorography);
      Photography of a fluorescent screen by means of a special camera and film, for example, 70 mm × 70 mm or 100 mm × 100 mm (in most instances specifically adapted for x-ray procedures).

C. X-ray Cinematography and Videotaped Images

1. X-ray image intensifier cinematography.
   Motion pictures of the image intensifier exit screen with a 16 mm or 35 mm cine camera at frequencies of up to 50 frames per second (also known as high-frequency or high-speed cinematography when the frame frequency is between 50 and 500 frames per second).
2. Intensifier television cinematography.
   Motion pictures of a monitor screen from an image intensifier fluoroscopic installation (see A3) on a specially mounted 16 mm camera with frequencies of 12.5 or 25 frames per second.
3. Videotaped recordings.
   Videotaping of the images of an IITF installation for repeated replay on a television monitor. (Scenes recorded in this manner can then be permanently recorded on film by methods mentioned in B2b or C2.)

D. Computer Tomography

Visualization of a thin cross-section of the body by means of a computerized tomographic scanner. It measures differences in x-ray attenuation and presents them in the form of an image on a monitor. Permanent records of the (attenuation) image are made by means of a polaroid camera or other photographic recording techniques.

Other Imaging Systems Using Ionizing Radiation

Certain radioactive substances emit radiations whose quality is comparable to x-rays. A number of these substances are known to accumulate in specific organs after corresponding administration, either in food or by injection into the bloodstream. It is possible to image such accumulations by means of special imaging systems (for example, linear motion scanner or gamma camera). Form, shape, and size of the organ are visualized in this way. As a rule, such an image yields different information from that obtained in radiographic procedures. Radioactive substances are also used in physiological studies. These are nonimaging examinations.

X-ray Examination with Contrast Media

The abdomen as well as hollow organs filled with fluids (e.g. blood, urine, bile, lymph, spinal fluid) can only be delineated rather poorly in the radiograph without appropriate aids because the difference between their density and chemical composition and that of their surroundings is too slight. Therefore, in certain x-ray examinations, we are impelled to change the contrast presentation of body fluids in hollow spaces by means of contrast media to achieve improved recognition.

One can use as contrast media substances which more readily attenuate x-rays than the surrounding soft tissue ("positive contrast media") and others which attenuate less ("negative contrast media"). Double contrast is attained by using positive and negative contrast media simultaneously. First a surface coating with a positive contrast is made, followed by inflation of the hollow organ with a negative contrast medium.

Different methods are available to transport the contrast medium, which must be administered in nontoxic amounts, to the desired location in the body.

1. Accumulation of contrast media in the desired location due to metabolic processes followed by excretion. Dispense via:
   a) the mouth (per os, oral);
   b) injection into blood vessels (in veins: i.v. = intravenous; in arteries: i.a. = intraarterial).
2. Dispensing directly into the organ under examination (hollow organ or hollow space) via:
   a) anatomical orifices (e.g. the mouth for the gastrointestinal tract or the larynx for the tracheobronchial system, the anus for the colon, the vagina for the uterus and through fistulas or artifical openings);