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One century of diagnostic imaging in medicine

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Abstract. The historical outline shows the development of radiologic diagnostics from the early Roentgen days up to this centenary. The roots of radiologic diagnostics go back to the European Renaissance. It is a history of medical pattern recognition and functional analysis by several methods including X-rays, ultrasound waves or strong magnetic fields. The difference between conventional radiographs and a picture reconstructed after digitalization, with several possibilities of postprocessing, is explained. Research and further technical revolutions, like the development of semiconductor elements and computers or tailored contrast media, sophisticated pictorial representations and perceptions, are among the cornerstones of imaging diagnostics. During this century many diseases have changed their manifestation and spread. This is illustrated by tuberculosis and cancer and highlights the growing importance of imaging diagnostics and interventional radiology. The thorny path to independence of radiology is also a history of the medical establishment's resistance.
Key words. Radiologic diagnostics; imaging methods; pictorial representation; Roentgen computerized tomography; interventional radiology; computer models.

Before the medical use of Roentgen rays (X-rays), other physical examination methods, and surgery, enabled us to have a restricted insight into the interior of the human body for diagnostic purposes. Known since antiquity and the European Renaissance, these techniques were substantially developed in the 18th and 19th centuries. The physician's fingertips became eyes during palpation of the patient's body. Through changes in sounds within the chest and abdomen (auscultation), various disorders of the lung, heart and intestine could be recognized. Percussing the chest and abdominal wall also contributed. By the end of the 19th century speculum examination of the inner surface of the eye was well developed, while endoscopy of body cavities and hollow organs was in its infancy. Besides other criteria, like changes in analytical chemistry and additional laboratory findings, or conditions of the pulse and temperature, a patient's history (anamnesis), i.e. a process, contributes decisively to the diagnosis.

Roentgen diagnostics in the pioneer days

The very limited possibilities of morphological and pathological diagnostics of those days met the revolutionary physical examination technique via the surprising phenomenon of body-penetrating X-rays[9,36]. In accordance with natural differences corresponding to the individual 'Roentgendensity' of the different body structures, X-rays produce shadow casts of the more radiodense body structures by direct exposure of plain film or fluorescent screens. The previously dreamed-of noninvasive insight into the interior of the patient's body was now a reality. Roentgen-rays are certainly no 'X' anymore. After 100 years they should be named after the unselfish discoverer who merits this honour. In 1975 this was granted to G. N. Hounsfield with the use of 'Hounsfield-Units' in computerized tomography (CT). Other examples are the basic SI units (Système International d'Unités) using derived SI units since January 1 1986. They are named after famous old pioneers in radiation physics and radiobiology like Gray (Gy) and Sievert (Sv) or Tesla (T), as a new unit of magnetic flux-density (induction). Unfortunately the 1937 term of 1 Roentgen (R)[31], that defined an amount of radiation (primary ionisation of air), was swept away with the new units in 1986. From that time on the term 'Roentgen' has disappeared from physical definitions. It is the same with the old unit of atomic disintegrations per second in radioactivity, defined since 1930 in Curie (Ci), now in the new SI-unit Becquerel (Bq) (see Roth, Fritz-Niggli and Rösler in this issue).

Reflecting on this we should consider the beginning and background of one century of efficacious radiation physics, biology and diagnostic success in medicine. The Roentgen method was obtained by 'trial and error', verifying observations on the human and scientific theories of maladies, morphology and function. Rational pathology sees in this light the 'seat and causes of many diseases as the anatomist identifies them'[78], as a local process. Thus pathology becomes recognizable by changes of morphological pattern and function. In this concept the diagnostician has to look primarily for pathological-anatomical organ findings and functional alterations (see Rösler in this issue).

The spiritual fathers of the localistic theories[7,19,78,96] were above all the anatomist Andreas Vesalius (1514/15–1564), the anatomist and pathologist Giovanni Battista Morgagni (1682–1771), the ingenious French physician and founder of histology M. F. Xavier Bichat (1771–1802), as well as Rudolf Virchow (1821–1902) who combined cytology with pathology, known as cellular pathology[97]. The outstanding success of surgery confirmed this scientific concept in the second half of the 19th century. A specialized organ pathology and the disease model of organic medicine were the result. They continue to have an effect on the scientific fields of twentieth century medicine. Functional and organic diseases are not opposites anymore, but the expression of different points of view. In one case there are morphologic features in the foreground, in the other metabolic changes. The evaluation, however, is subject to changes due to the process of disease and the increase of knowledge.

As the centre-piece of medical radiology, imaging diagnostics has its roots in radiological physics and biology (see Roth and Fritz-Niggli in this issue). Besides, these basic sciences check and optimize radiodiagnostic working methods in terms of radiation exposure, protection and by quality control. Anatomy, pathology and pathophysiology show the value of morphological and functional statements constantly being compared with their controls. That is why these disciplines are fundamental parts of the radiologist's basic training. It is mainly those medical disciplines which treat localizable diseases that benefit from this in favour of the patient, and they follow the development of the diseases under therapy in surgical specialities or medical oncology, radiooncology (radiotherapy) (see Birkenhake and Sauer in this issue) and so forth. Of course, radiological and pathological-anatomical findings are not synonymous with the complex pathological process. They are but elements in a total process. The whole is more than its parts, as illustrated by Gestalt-psychology. We only partially understand the complex web, and holistic philosophies have to withstand continual examination of their falsifiability as ideas of the burden of proof fluctuate. Specialism and research of form and function in imaging diagnostics are linked here. Radiation here belongs to a group of physical, precisely defined immaterial measuring tools, which are used by the physician in this medical branch with limited, defined objectives. Studying the special medical literature of the pioneer days is still impressive for its multitude of ideas and their fast spread, but also their realization delayed for decades[2,7–9,11,17–19,26,31,36–41,53,60,68,78,85,89,90,95–97,100,103,109].

Radiation dose, direct film exposure, radiation measurement and imaging

As early as the First German Roentgen Congress in 1905[39,99], Friedrich Dessauer (1881–1963), a medical physicist and cultural philosopher who emigrated to Switzerland after 1933, demanded the setting up of a commission for the fixing of standards to measure the intensity of X-rays. In 1909 the almost forgotten Swiss mathematician and physicist Th. Friedrich Christen (1873–1920) held his probation lecture in Basel on 'The distinctness of an X-ray print as an absorption problem'. A little later he defined a measure for the quality and homogeneity of radiation as well as for absorbed radiation – i.e. amount of energy deposition into a unit volume of substance (refs 26, 104; see Roth in this issue). Researchers and technicians, however, could not reconstruct a versatile processable print from exact measurements of the attenuated transmitted radiation and their digitalized values until six decades later with the advent of advanced computer technology. It is called Roentgen computerized tomography (CT). Since 1970 all the body sections which are required for the exact location of a region of interest can be depicted on digital reconstructed cut sections without overlap (fig. 1). Up to that time X-rays directly exposed the light-tight covered photo plate (conventional plain film), being reduced by the transmission through the patient's body. In this direct 'transmission imaging' there origi-

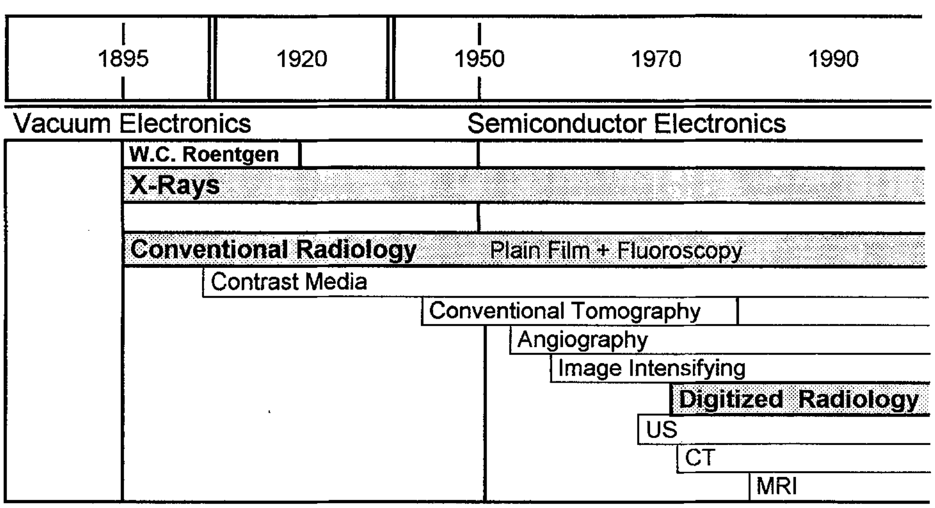

Figure 1. Development of clinical diagnostic imaging.

A

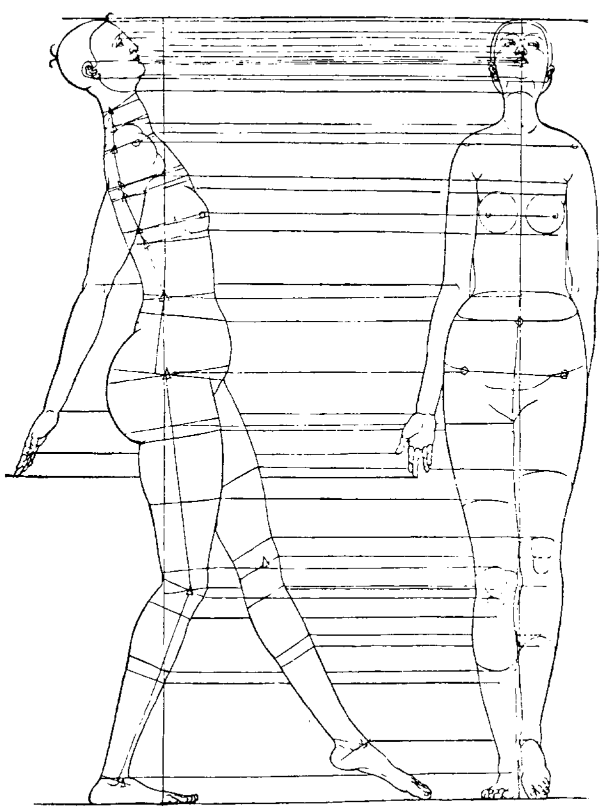

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Figure 2. *A* A. Dürer, 1525[24a]. His perspective apparatus shows the projection geometry of the lute into the frame (i.e. like the level of a plain film) from this point of view (the X-ray source would be more to the left of the lute!).
B A. Dürer, 1528[24b]. Proportions of the universal and the particular of the human body in profile and in frontal view. Individual details in different projections are also fundamental in radiological diagnostics.

nated shadow casts of interior organs in central projection, like those in Albrecht Dürer's (1471–1528) 'Instruction of Measurement' (1525)[24] and his 'Proportion Theory' (fig. 2A, B). The prospective radiologist has to learn to read plain films with the structures of the penetrated body part which is projected in a plane in order to be able to give the referring physician a correct Roentgen diagnosis. For this the provisional Roentgen diagnosis from the film information and diagnostic knowledge must first be worked out. The concluding identification of radiologic alterations with actual pathology on the basis of experience[106,107] then leads to the definite diagnosis. Such complex processes of visual perception and analysis of image prints of course hold various possibilities of deception and errors. The interpretation refers to the image perception and not to the image itself. Footprints – i.e. image prints by radiation – are not the same as the living foot. The diagnosis of the different footprint readers inevitably sometimes differ. Antoine Beclére (1856–1939), the doyen of French radiology, however, recorded the unalterable starting-point of the method: 'X-rays do not lie. We can be deceived by not understanding their language or by demanding statements from them which they cannot make'[5,104].

The relics of X-ray technique in the old Roentgen cabinets of the pioneer time, which were stuffed with equipment and cables are fascinating[2,5,9,11,17,18,26,37–39,54,68,88,95,100,103]. With coloured light apparitions in the not yet highly evacuated X-ray tubes, the flickering ion tubes, the rattling and crashing high voltage discharge lightning by sparkover and the emerging smell of ozone, we are more reminded of Faust's study than of a modern medical examination room. For the patient as well this gives the fascinating and frightening impression of a medieval alchemist's kitchen. At that time X-ray technique was first of all a question of the tube. Only with experience, and by feeling its 'moods' during operation, can it be mastered by physicians, physicists, nurses, radiographers and hobby technicians[2,8,9,11,17,37,68,88,100,104]. For this the tube power has to be determined from the existing range by the fluoroscopic quality on one's own hand. One's own hand served as a reusable test object. The early skin reaction of sunburn was followed after a longer latency period by radiolesion, often with agonizing infirmity for years. The German radiation pioneer Alban Köhler (1874–1947) reports in his memoirs how he met John F. Hall-Edwards (1858–1926), the Birmingham radiologist, at a medical congress, 'but unfortunately could not shake hands with him, because both his hands were amputated'. Unforeseeable systemic effects of the new radiation mark the tragic story of the martyrs and victims of the Roentgen pioneer time[26,31,68,76,99,100,104,107] (see Fritz-Niggli in this issue).

Through all odds, misjudgements, preconceived ideas and wrong directions, Roentgen tubes, technology and methods have undergone many radical changes. On the other hand most of the diagnostic institutes in Europe used the old ion tubes (cold-cathode tubes) until far into the 1920s, although the American physicist William David Coolidge (1873–1975) achieved consistent tube power even in 1913. His highly evacuated hot-cathode tube improved the quality of X-ray imaging dramatically[8,18]. But economic limitations – like post-war conditions – slowed down several innovative thrusts.

Pictorial perception

Careful and systematic observation as well as a profound prior knowledge are the fundamentals of pictorial perception (see fig. 2B). Nevertheless pictorial perception is not a purely rational process. Moreover the general impression is that a lot of factors are important: memory, expectation, attention, fatigue, proportions, sense of form, symmetry relations, contrasts, recognizing familiar anatomical and pathological outlines and figures etc. Therefore the radiologist must know on the one hand where to find a trait and on the other hand must be able to distinguish between the normal, modifications, variations, and the onset of pathology. But images are not self-evident. Only by perpetual training, comparing normal anatomy and physiology with its pathological counterparts, is a clear diagnosis possible. The principle of the old radiologists is still valid: 'You only see what you know!'

A three-dimensional conception of forms and position relations of the organs was first achieved by applying the diagnostic-ray on two-dimensional radiographs from different perspectives or by a rotational screening. Nowadays this is made possible by many parallel digitized body intersections of computerized tomography (CT) and (pseudo-) three-dimensional reconstructions. Virtual computer graphics can present us with seemingly three-dimensional views, thus simulating reality according to computations. Each written report of the image analysis – the extract with which we continue on another diagnostic level – is reduced to a few lean sentences. Only the aspects that are regarded as relevant are picked out. They never reach complex factual reality or the enormous scope of information of a pictorial document, for 'A picture says more than a thousand words!'. Like the artist (see fig. 2A, B) the radiological imager first acquires a feeling for forms and proportions of human structures by training with exact measurements. Thus pathological deviations from the standard range can be recognized even if later not every particular case is measured any more. This developed sensitivity is partly beyond the criteria of scientific analysis and is a characteristic of several medical activities.

Registration of morphology; tuberculosis (TB) and skeletal diagnostics

How frightened of TB people and above all 'predisposed families' were even around 1900 is hard to imagine today. This is reported in impressive biographies and other literature of the history of medicine. Other sources are medical specialist literature or information on the cause of death in church books[5,8–10,19,38,46,54,68,70,81]. Up to then TB was one of the most frequent causes of death in the developed countries (approx. 270 deaths per 100 000 inhabitants per year). Therefore radiologic diagnosis of pulmonary TB belonged to the most frequently used radiological examination of that period, followed by those of pneumonias and heart diseases. The well-known Heidelberg clinician Ludolf Krehl (1861–1937) confirmed the achieve-ments of radiodiagnostics in TB prevention, early detection and follow-up: 'Radiology brought enormous progress', and, more than all the other examination methods together '..., it contributes a main part to the success'[70]. Even before the tuberculostatica era after 1950 TB decreased steadily, interrupted by new peaks in both World Wars and post-war eras (approx. 1 death per 100 000 inhabitants per year in developed countries in 1991). Opinions are divided as to whether the decrease was mainly due to sanitary measures, healthy life-style, improved feeding and thus the patient's improved immune system, or to medical treatment, or a toxicity change in the microorganism responsible. Accordingly the amount of radiodiagnostic service providing mass screening for TB prevention and early detection decreased in the second half of the century. However, it seems a change in the trend, with increasing multiresistant TB cases, has begun to show in recent years – probably in connection with hypoimmunity as in AIDS. In the world population of more than 5.4×10^9 people at present (in 1900 1.7×10^9, in 1930 2.1×10^9, in 1960 3.0×10^9), about 3×10^6 die per year from TB world-wide. About one third of the population is infected with the bacillus. In some African countries TB is one of the most frequent epidemics, additionally favoured by AIDS. Changes in spread of this disease illustrate the present importance of pulmonary radiological diagnostics in the third world.

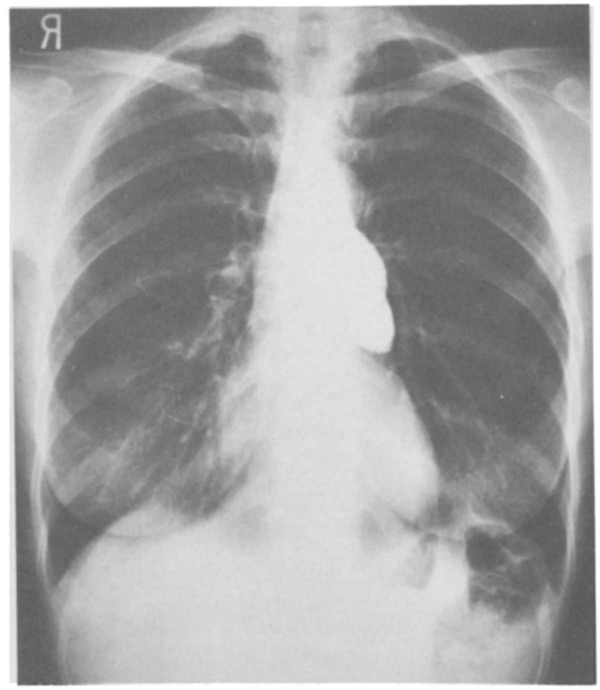
The high roentgendensity of bone-structures gives a fine linear resolution in skeletal radiology[2,9,11,17,26,31,53]. Therefore bone fractures were among the first radiological diagnoses. Even the static bony meshwork becomes visible on the X-ray film. Pressure forces model the individual osseous trabeculae like iron constructions over large platform halls. Today bio-mechanically experienced physicians and specialists in metabolic disturbances, together with radiologists, examine their structure, thickness and dynamic in time and age under changing load (see Rösler in this issue) in sportsmen or after injuries, in osteomere transfer, endoprothesis replacement or in osseous variations, malformations and ageing processes. Traumatologists and orthopedic surgeons use such information together with pressure and tension analysis in their stabilizing treatment. In the young scientific discipline of bionics new technical solutions are searched for from biological findings with electronic simulation. Plain film skeletal radiology has kept its great importance in general practice. Today it is complemented by previously unavailable information. Several digitizing tomographic methods give insight into interior and surrounding soft tissues, and complex injuries can be reconstructed pre-operatively by means of pseudo-three-dimensional (3D) computer images. Any diagnostic process has particular difficulty in the transition range between the still normal and the beginning of pathology[66,68,99].

Plain film, fluoroscopy and examination tactics

Since Roentgen's discovery the technique of fluoroscopy (radioscopy), which presents movement processes on the fluorescent screen in real time, has been added to the overview of the directly exposed conventional plain film. Additional 'exposures in sight' (snap-shots) document the screening findings from several positions. For example, image information about benign pneumonic or malignant carcinomatous infiltrations, their position and extension or lung metastasis of cancer is complemented by the detection of pathologically changed respiratory movements of the diaphragm and lungs or a passage stop in the esophagus, if the cancer invades this organ. In addition to heart form and size, disturbances of heart- and aorta-wall movements as well as of lung perfusion (see Rösler in this issue) can be identified in innate or acquired cardiac defects[20,42,54,77,105,109]. Plain film and fluoroscopy are among the most important diagnostic examinations. These examination tactics have changed fundamentally in the second half of the century because of radiation protection. Now, with the help of medical pre-examinations and plain film overviews, it is decided whether a well-directed complementary screening based on a precise formulation of the problem is necessary or whether other examination methods from the wide range available – like digital tomographies – lead immediately to a faster and more precise diagnosis. But up to now the plain chest film (fig. 3A, B) is the most frequently requested radiological examination, followed by skeletal exposures.

Contrast and contrast media (CM)

The contrast resolution of the conventional plain film is not enough to distinguish soft tissues in the head, the abdominal cavity and the extremities from each other. Thus in the beginning neither gastro-intestinal tract,



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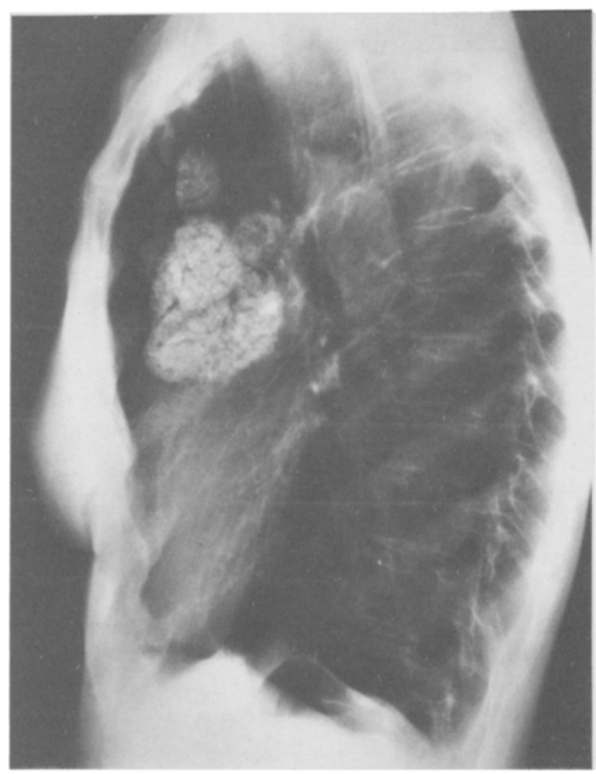

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Figure 3. *A* Frontal view of a human thorax: soft tissue density of the heart, abdomen and fine striations of lung structures; bone density of the ribs and vertebral column; compact calcium density (white) of calcified lymph nodes.
B Same female patient, same time, lateral view of the thorax. Calcified lymph nodes two years after radiotherapy of Hodgkin's lymphoma (necrosis–calcification!).

Figure 4. Arteriography of the legs using Positive CM. Embolic obstruction of the artery on the right side (R) below the knee joint.

brain, spinal marrow and nerves, nor blood and lymph vessels, lymph nodes or further soft tissue organs could be recognized. On the other hand calcified bones, calcifications in soft tissues (see fig. 3A, B) or renal and biliary calculi, finest densifications in air-containing lung tissues[62] or metal-dense foreign substances, like splinters, projectiles and prosthetic devices and shadow-casting spare parts, were readily visible. Based on their very different radiodensities and the resulting contrast, as compared to transparent air-containing lungs or radiologically slightly radiodense soft tissues, the radiologist can distinguish between them.

In many internal diseases in the region of soft tissues, radiological examinations cannot begin without the development and administration of shadow-casting, using well-tolerated substances. Such contrast media (CM) attenuate X-rays more (fig. 4) – or less – than the molecules of the constantly slightly radiodense background soft tissues (atomic numbers mostly 1–16), depending on the atomic number of the marker atom in the molecule. The higher the atomic number, the more the attenuation of X-rays. Thus new contrasts appear on the Roentgen film after X-ray transmission. Roentgen CM (RCM) are injected in specific body cavities and organ systems or – as in gastro-enterologic examinations – they are swallowed or reversely infused into the rectum via the anus. After first attempts by W. B. Cannon (1871–1945) in 1896[13], the Munich internal specialist Hermann Rieder (1858–1932) dared this step in 1904 by mixing bismutum subnitricum and bismutum carbonicum, the so-called 'Rieder meal'[8,9,33,51,52]. In 1910 bismuth (atomic number 83) and other heavy metal compounds, which sometimes produced side-effects, were replaced in gastro-intestinal diagnostics by Paul Krause (1871–1934) with the insoluble and non-absorbable barium sulphate (atomic number Ba 56). It continues to be used today. In the beginning, dirty preparations of barium sulphate cause toxic incidents which could only be avoided with the making-up of highly cleaned 'purissimum'. That was a problem of early chemical preparation. At the Seventh German Roentgen Congress in Berlin in 1911[51] George Fedor Haenisch (1874–1952), a student of Albers-Schönberg's in Hamburg, presented his fluoroscopic examination of narrowing of the large intestine by carcinomas using an enema of bismuth suspension. Besides many others, radiologists of the Viennese school[29,101] under Guido Holzknecht (1872–1931) and Martin Haudek (1880–1931) developed such examination methods further up to the 1920s. The characteristic 'Haudek's niche' was described in 1910 and later the Swedes Gösta Forssell (1876–1950) and Ake Akerlund (1887–1958) engaged in the field[1,6,33,35,52,90,109]. It turns out that the frequency of pyloric ulcers was initially highly overestimated, whereas duodenal ulcers were far more frequent in reality. Gastric surgery has been supported to a great extent by radiologic diagnoses. Gastric cancer gets a secure diagnosis which is almost independent of the often rare clinical symptoms and signs. Here radiology has proved its value.

In Berlin from 1905 on Alexander v. Lichtenberg (1880–1948) and Fritz Voelcker (1872–1955) tried the CM-visualization of the urinary bladder and the other diverting urinary passages with reversely injected colloidal silver preparations. However, after the occurrence of damage to the mucous membrane, they were replaced by substances with fewer side-effects. Among these are sodium and potassium iodate solutions with which the first angiography in a living human was carried out in 1919. E. A. Graham (1883–1957) and W. H. Cole (1898–1954) used bromophenolphtalein compounds, which are discharged via liver, from 1923 for cholecystography[8,9,31,41]. Nevertheless, the greatest practical value is shown by the numerous easily synthesized iodine organic X-ray CM which are removed by the kidneys. From 1929, using an intravenously injected mono-iodine pyridine compound, Moses Swick (born 1900), A. v. Lichtenberg, L. Lichtwitz and collaborators introduced to general practice the Roentgen imaging of the urinary system in a physiological condition, the so-called excretion-urography (intravenous urography). Iodine (atomic number 53) is the contrast-giving 'marker' in these organic-chemical compounds. Up to the 1950s the di-iodised organic CM, which were developed around 1930, were used and were then replaced by tri-iodised molecules with decreased toxicity and increased contrast density. Before suitable substances can be used in a human a lot of animal studies are necessary.

Morphology and function

In gastro-intestinal examinations, fluoroscopic techniques using contrast media and additional snap-shots with the patient in various positions are among the examinations which are relatively easy and cheap to perform. They are nowadays complemented or partly replaced by endoscopy and various digital tomographies. Since the middle of the century further developments in CM have made more exact analyses possible. They include previously unrecordable dynamic processes, like direction and velocity of blood flow, in single organs and other distinct, radiologically controlled places. Here too, technological developments today offer the possibility of morphological and functional analysis with series of digital slices in rapid sequences. Sometimes dynamic changes occur at an early stage of disease, before a morphologic focus can be recognized by eye. Then the cause must be investigated, using extensive clinical experience and often high diagnostic expense in order to identify the hidden foci at a therapeutically favourable early stage.

Dynamic processes are recorded by other radiologic methods as well. Before 1909, Franz-Maximilian Groedel (1881–1951) recorded movement processes cinematographically. The 'movies', which can be replayed as often as needed without further exposure of the patient, were first directly recorded on an exposed film. Then, between the World Wars, Robert Janker (1894–1964) developed indirect Roentgen-cinematography with coordinated movements which were photographed from the screen. After the middle of the century they were transferred to other image stores like magnetic tapes and opto-electronic discs[8,9,18,26,31,35,41,47,53,104,109].

The fight for independence of medical radiology

New ideas and working methods inevitably produce new ways of dividing labour, specialization, and an increase in competition, centrifugal efforts and plans of self-realization. Such developments continue within new specialized branches. They cannot be influenced by dilettantism and joining a discussion about problems one hardly understands. Low competence, arrogance and quackery or charlatanism go hand in hand. New situations require rather a process of rethinking and cooperation between equal partners among specialists and generalists, or a fragmentation of our knowledge and skill emerges.

The reality was that clinical chiefs of internal medicine or surgery delegated young physicians as 'Roentgen-slaves and dark-room men' for decades under their strict direction. The chiefs themselves were seldom familiar with the methods and problems of diagnostic radiology. Mostly the radiologists had bad working conditions in cellars. In Europe especially medical superintendents for a long time underestimated this work as a solely technical subsidiary service. Still in 1961 the Cologne internal clinical specialist H. Schulten[91] thought that the radiologist is only 'a technical adviser of the physician in charge, there is no other way'. Under such conditions an actual school of radiology could not emerge. In this context it is not surprising that levels of diagnostic research, results and radiation protection were pitiful in several European hospitals and universities. Who should commit themselves to special questions of radiology if not competent, full-time employed radiologists? Were not the representatives of other disciplines working to full capacity dealing with their specific problems? It is quite heartening to hear of other convictions and tendencies, which I mentioned previously about the famous Heidelberg clinical physician Ludolf Krehl, and which I also know of with regard to the Sauerbruch school. For years I have experienced a professional relationship of equality between partners in Basel during many visits with the prominent surgeon Rudolf Nissen (1896–1981) and the Viennese radiologist Erich Zdansky (1893–1978).

In Scandinavia and the USA a more pragmatic approach can be found to the independence and organization of radiological centres, further training, introduction of technical innovations and financial management. As early as 1901 the New York Post-graduate Medical School established a chair of radiology. On the other hand G. C. Johnston[60] described in 1909 the situation of a radiologist before the American Roentgen Ray Society (ARRS) as follows: 'The roentgenologist is usually a beloved crank. Few of them have any business sense. . . . The apparatus of today is obsolete tomorrow. There is a constant race between our pocket books and the inventive genius of the up-to-date manufacturer'. In Central Europe the Viennese School took precedence. The Austrian Roentgen pioneers Guido Holzknecht (1872–1931) and Robert Kienböck (1871–1954) presented a memorandum to the Viennese Medical Faculty in 1903[55] in which they ask for a 'special training' for the extensive discipline of radiology, and its independence. In Vienna this request succeeded. Elsewhere further generations of radiologists had to fight for the 'speciality in medical radiology'[26,29,39,56,89,90,101,104]. Max Levy-Dorn (1863–1929) took up the question again at the Tenth German Roentgen Congress in 1914: 'The radiologist is a specialist like any other medical specialist among physicians. Intervening in other specialities is common to all specialists. Fragmentation of knowledge and ability in medicine brings the necessity of a frequent cooperation of many physicians . . .'. The Zurich radiologist Hans R. Schinz (1891–1966), in a personal statement at the Thirtieth German Roentgen Congress in 1939, pointed out that all the speakers from several medical branches had only spoken regarding their own interest. 'It is strange, that in Germany, the very country of Roentgen, the discipline of medical radiology is fought against and suppressed'. In Zurich H. R. Schinz was subordinate to the head of the surgical clinic until 1942. Then he succeeded in getting an independent university radiological centre and a full chair for medical radiology despite all opposition[89]. In Strasbourg, Charles M. Gros (1910–1984) established an official chair with medical radiology as an examination subject in the finals in 1955[98], in Basel in 1965, and at the University of Freiburg, Germany with the appointment of W. Wenz (born 1926) only in 1972. Ninety-nine years after Roentgen's epochal discovery there is no chair for radiodiagnostics at the German university of Erlangen-Nürnberg[108]. These difficulties on the way to independence from other medical specialities persisted throughout the whole century. Meanwhile the independent and centralized radiology of Scandinavia, or the university roentgenology of the United States have achieved a high level of performance.

The 'dark Roentgen era' is dead

In many respects radiodiagnostics remained quite conventional in practice up to the middle of the century[8,9,18,31,109]. Since then the thrust of development with semiconductor electronics and computerization has made new methods and concepts available as well as new diagnostic insights. The low brightness of the old Roentgen-screen up to the late 1950s – today unimaginable – corresponded to the light intensity of a moonless starry night. At first with very small mirror reflectors, then later with high resolution large field image-intensifying screens and television networks (TV), examinations can be performed in an illuminated room with almost 1000 times enhanced images. With this the detail recognizability is improved decisively for the examiner. Simultaneously the patients feel more relaxed with the examination in a lighted room. With further intensifying technology the X-ray exposure considerably decreased[8,9,26,31,39,53,98,103,104]. Here only a few lines of development can be highlighted in 1) pulmonary radiology, 2) cardiovascular, and 3) gastro-intestinal radiology.

Pulmonary radiological diagnostics

Besides routine projections in diseases of the chest, conventional tomography and direct CM-delineation of the bronchial tree (bronchography) gained relevance in practice in the 1930s and 1940s[9,27,31,53,109]. Tomography allows the visualization of a particular tissue layer in a definite body slice by special movement techniques. That makes it easier for the radiologist to identify pathological alterations. Its development originates from examinations by the Dutch electrical engineer, neurologist and hobby-radiologist Bernard G. Ziedses des Plantes (1902–1993) in 1931. This technique remained a standard method up to the 1980s. Then it was more and more replaced by several methods of digitalized tomography.

By comparing preceding images and follow-ups, we receive a pictorial longitudinal section in time of the individual pathological process. It has a great prognostic importance as a fourth dimension of documentation and is a valuable factor in treatment[77,85,106,107]. In this period the emphasis of diagnostic efforts shifted from infectious lung diseases, especially TB, to the increasingly common bronchial carcinoma. Exact localization is a pre-condition nowadays for an ultrasonographically or computed-tomographically guided puncture for histological, histochemical or cellular determinations[53]. Thereby we get more specific information of the individual tumour biology and biochemistry as parameters of diagnostics and for therapeutic actions. Nevertheless it remains open, whether radiology with its future potential will be the appropriate means for genuine early diagnoses. At the end of the century this medical problem is still unresolved. This is proved by the statistics of morbidity and mortality which show that, despite all the research expenditure, cancer mortality rate has increased in Switzerland from about 7% around 1900 to 12% of all cases of death in 1930 and 27% in 1992[10]. Similar figures are true for other industrialized countries. More than two thirds are attributable to bronchus and lung cancer in the male.

The way of angiocardiography

Cardiovascular diseases as a cause of death in Switzerland went from 23% in 1930 to 44% of all causes of death in 1991. Other industrialized countries give similar figures. An improved registration by new diagnostic methods is only a minor factor in this increase. A genuine increase in circulatory disturbances – like the ominous cardiac infarction in the male – is reflected in this 'killer no. 1'.

Imaging cardiovascular diagnostics have to answer some fundamental questions first:

1) More exact data concerning circulatory physiology have to be obtained.
2) Appropriate ways of access to the system have to be tested.
3) More tolerable CM have to be developed.
4) Various pre-conditions regarding technical equipment have to be met.

Only a few names can be mentioned, which are linked with this phase of low-risk examination methods, farseeing ideas but wrong tracks too[8,12,19,26,27,31,34,39,41,43–45,79,82,93,98,103,104,105]. The development of angiography is based mainly on physiological research and systematic animal experiments, and was first used in humans in the 1920s and 1930s. In 1929 the 25-year-old German medical assistant and surgeon Werner Forssmann (1904–1979) in a brave self-experiment tested the access to the right heart via a brachial vein. He surprised himself at how easy and trouble-free this procedure went. As CM he used a monoiodised pyridine derivate 'Uroselektan' of Schering-Kahlbaum. This can be regarded as the original model of a kidney-passing CM. His publication, however, was ignored. Further important contributions originated from the Portuguese school, from E. Moniz (1874–1955), L. de Carvalho, A. Lima and R. dos Santos[9]. They used the excellently contrasting CM thorotrast, which is without perceptible side-effects in the short term. But it is a radioactive material and emits alpha rays (see Rösler in this issue). In its colloidal phase it is accumulated in the reticuloendothelial system (RES) of the liver, spleen and bone-marrow. There it causes a high radiation-exposure at the cellular level over the following years. The risk of side-effects was misjudged in spite of early warnings. It was used in many countries up to the early 1950s. After a latency period of some years to decades several patients developed liver cirrhosis and/or malignant tumours.

But still there was no access to many vessel areas. Placing a catheter in the required spot without intense dilution of the CM in the vascular circulation was required. Only 10 years later when the French cardiologist A. F. Cournand (1895–1988) and the American physiologist D. W. Richards (1895–1973) again took up Forssmann's method, did angiocardiography go on. Then in 1953 the Swedish radiologist S. I. Seldinger (born 1921) had a decisive idea. In a momentary intuition, he pushed forward a flexible guide-wire in the puncture-cannula. Then he removed the cannula and placed a catheter over the guide-wire to the site of investigation in the circulation system. After the removal of the wire he injected CM through the catheter, simplifying the technique. Controlled catheter placement and rapid CM-injections (see fig. 4) have become cornerstones of cardiovascular radiology[93]. Since the 1950s better tolerated and more contrast-intense triiodised organic CM-compounds[27] have replaced the diiodised ones introduced in 1931. Then with rapid film-changers, image intensifying, TV and X-ray cinematography[9,18,53], the morphology of the whole vascular system and the dynamic of CM-flow have been investigated.

While arterio- and venography had been developed over 20 years, a clinical lymphography is prevented by problems of proper CM and technical difficulties with direct preparation and puncture of tiny lymph-vessels, even with assistance of the magnifying glass. After the British surgeon J. B. Kinmonth solved those difficulties in 1952[64], direct lymphography became generally accepted in practice by about 1960. It also gave new impulses to other areas of lymphology which triggered important progress between 1960 and 1980 in an up to then hardly known field[28]. The exciting atmosphere in 1966 at the First International Symposium On Lymphology in Zurich remains unforgettable to the participants of the meeting[86,87]. On this occasion the International Society of Lymphology (ISL) was founded[71]. Lymphography gives information about the normal or pathologic lymph flow and the fine lymphnode structures. More than simply the growth of knowledge, the method is helpful in early diagnosis of systemic lymphoreticular diseases and lymphnode metastases of cancer with exact localization of pathologies, therapy planning and judgement of special therapy systems in follow ups. But again only some important sections of the lymphatic system and parameters of pathology can be covered. Direct lymphography began to be replaced by digitalized tomographic methods around 1980[28].

Gastro-intestinal radiologic diagnostics and endoscopy

In the 1930s statistics record increasing frequencies of gastric carcinomas at up to 30 to 75% of the total cancer mortality. Since then the morbidity and mortality of gastric malignancies have clearly decreased. Today the mortality rate of gastric cancer in the male is only half as high as that of the increasingly common colo-rectal cancer. It is about one third of that of prostate cancer and less than a quarter of broncho-pulmonal cancer which is also rising. The most frequent carcinoma in the female is breast cancer. With its upward trend despite all efforts towards early radiologic diagnoses and therapies it is almost five times more frequent than gastric cancer in the female. These numbers reflect a genuine change in the spectrum of disease of malignancies during the last century. The reasons are not clear and certainly not solely the result of better medical diagnostics and therapies or advanced age.

Morphology and motility of the stomach and other intestine are examined with constantly improved Roentgen methods in accordance with the Viennese model[9,29,52,101,107], the Swedish school[1,33,90,102] and the Berlin clinic[6,39,53,104]. Since the 1920s Gustav v. Bergmann's (1878–1955) medical clinic at the Charité in Berlin, in association with Hans Heinrich Berg (1889–1968), has taken a leading position based on mucosal relief studies with changes in CM-filling, dosed compression and spot-film technique under fluoroscopic control. It is not just stasis, gastric dilatation or spasticity that facilitate an earlier diagnosis of gastro-intestinal ulcer, inflammation or cancer, but also the direct evidence of fine structural abnormalities. Probably the first attempts at intestinal double contrast examinations were done in 1921 by Hugo Laurell in Upsala, Sweden. But his publication was not widely read, because it was in Swedish. In 1923 the German surgeon A. W. Fischer[32] succeeded with a double contrast enema of the colon. He coated the intestinal wall with CM and immediately dilatated the lumen by air insufflation. So he got a transparent and expanded wall of the intestine with better recognition of tiny ulcerations and very small polyps. Pattern recognition and detection of small adenomas, polyps and early carcinomas of the intestine have become one of the greatest opportunities of radiology. Thirty years later this method was taken up and further developed in colon examinations as the 'Malmö method' by the Swedish radiologist S. Welin and his colleagues[102].

Since 1966 modifications of sophisticated double contrast techniques by the Japanese school with H. Shirakabe and H. T. Ichikawa have been valuable in the detection of early gastric cancer[35,61,94]. In this context radiology and fiberoptic endoscopy compete to prove their respective achievements. Endoscopy offers direct inspection of fine details of the intestinal mucous surface and local biopsy under view. Clear anatomical orientation within the whole gastro-intestinal system, exact localization of morphological pathology, and fine motility alterations, at least in terms of a submucous and organ-penetrating invasion into surrounding tissues, remain the strengths of radiology, together with the digitalized tomographic methods. All these examinations are now standard techniques in most medical centres. The less expensive gastro-intestinal radiological techniques without the 'big machines', remain dominant in the third world.

The 'golden age' of diagnostic imaging

After Roentgen's discovery the second revolution followed in the seventies, with the transmission measurement of X-ray attenuation by more sensitive detectors. Precise measurement, digitalization, secondary picture reconstruction from digital values and postprocessing are the fundamental principles of all the computerized tomographic systems allowing detailed characterization of tissues.

Roentgen computerized tomography (CT)

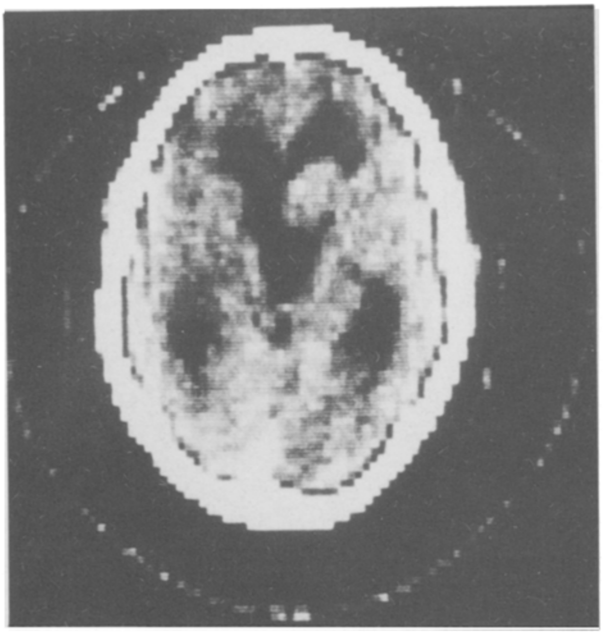
During World War II and immediately after, this second revolution was prepared by studies in the Bell Laboratories in the United States. Up to that time highly sensitive electronic tubes with a single function were used for controlling electrical currents. Now physicists and electronic engineers, including the 1956 Nobel laureate William B. Shockley (born 1910) and coworkers, looked for more discrete and robust semiconductor elements without such technical restrictions. The developmental steps included integrated circuits with hundreds of functions since 1959, microprocessors since 1971 and finally complex micrometer systems with millions of functions per chip. Since 1948 this electronics revolution has changed our information storage and transmission, techniques of systems control and steering mechanisms, and finally our working conditions, leisure and way of life.

The enormous reduction in size and cost, the increased speed of operations and data storage capacity enable us today to accommodate electronic equipment for medical mainframes, like CTs, in one switchboard panel. The old electronic vacuum-tubes in the 1940s would have filled a factory for the same capacity. Besides Roentgen-CT, digitalized, computerized and miniaturized X-ray technology developed further examination devices for modern imaging diagnostics. They are based on other physical principles (see Roth in this issue). Among them are ultrasound (US) and magnetic resonance (MR)[47,53,79,103,104].

At the central research laboratories of the Electric and Music Industries Ltd. (EMI) near London, the design team of the electrical engineer and former teacher at the RAF Radar School, Godfrey Newbold Hounsfield (born 1919), developed during 1958/59 the first fully transistorized British mainframe, and since 1967 the CT[58]. The preliminary work of various researchers goes back to the theoretical function tests of the Austrian mathematician J. Radon in 1917[84]. Each transmitted beam path is part of a series of simultaneous equations. From that a picture can be reconstructed in a matrix. Working on automatic military pattern recognition, Hounsfield had the idea of using penetrating radiation to explore structures in biological bodies[58]. For his first tests he used a dead duck and scanned its body for several hours with low dose gamma radiation. Conventional X-ray radiographs view the body from only one angle. Therefore several structures in the radiation path are superimposed. But CT machines use a thin, fan-shaped X-ray beam to penetrate slices of the body from many angles by revolving a Roentgen-tube around the patient. Measured values are computed in complicated equations, digitalized and assigned to an initially very coarse picture-matrix (fig. 5A) of a few squares[58]. Finally digital analogue converters (DAC) change the attenuation numbers to specific grey-tones or colours.

This way a picture of the structures within a thin body section is created without superimposition, which the anatomically trained radiologist can read. With its high contrast-sensitivity the CT captures much finer differences of soft-tissue roentgendensity than the conventional photo emulsion on a Roentgen film. Not only the grey and white matter of the brain and the fluid in the cerebral ventricles now can be seen, but also the site and extent of fresh and coagulated blood after cerebral bleeding or tumours, a surrounding edema or metastases.

On October 1, 1971, the first patient was examined by Dr. J. Ambrose with a prototype of the EMI-CT (EMI-scanner Mark I) at the Atkinson's Morley's Hospital in Wimbledon. In the beginning even experts could not see the usefulness of the new method of pattern recognition because of the low geometric (linear) resolution. They underestimated the importance of the high sensitivity of roentgendensity discrimination between several soft tissues[4,15,26,47,53,57–59,73]. But soon there was a run on the 'EMI head-machine', and the demand could not be



A

B

Figure 5. *A* Head – CT 1973. A transverse section of the head. Reconstructed picture with 80 × 80 matrix. Single matrix elements with distinct density values (Hounsfield Units, HU) are well visible. Brain tumour growing into the dilatated right sided cerebral ventricle.
B Whole-body – CT 1981. A transverse section of the upper abdomen in multicystic disease. 512 × 512 picture elements matrix. 1 = Left kidney; 2 = Right kidney; 3 = Liver. Dark holes = Cysts. Middle below (white) = vertebra. Before the vertebra = Abdominal aorta filled with CM.

satisfied. All the interested parties had to take their place in a queue and receive the equipment on a basis of first come, first served. After two further units in London and two other installations in the medical centres of the Mayo Clinic, Rochester (Minn., USA), and the Massachusetts General Hospital, Boston (Mass., USA), in June and July 1973, the first CT for cerebral examinations (see fig. 5A) on the European continent was used in Basel at the Kantonsspital, on December 20, 1973. This EMI Mark I costs 1.25 million Swiss francs, an enormous amount for one Roentgen machine at the time[26]. A little later the department of neuroradiology at the Karolinska sjukhuset in Stockholm got the next machine[50]. For the first few years no diagnostic experience was available to CT teams. They learnt by doing and comparing with other fields of medical diagnostics and diagnostic control. Soon the flood of requests from surrounding countries had to be restricted in Basel by the introduction of specific indications. When idiopathic epilepsy was added to the indication list of tumorous, inflamed or bleeding foci, the examiners were impressed by the frequency with which idiopathic epilepsies were identified as having an organic origin.

From March 9–14, 1975 the first international symposium on computerized cranial tomography took place in Hamilton, Bermuda: 'The purpose is to provide an opportunity for those who have had experience with computerized cranial tomography, to exchange information and ideas on the current state of the art, to explore and identify priorities in research and development, and to promote the best clinical utilization of this new radiological method of investigation'. At this symposium the Basel-EMI group reported on diagnosis and control of intracranial metastases by computerized axial tomography. On March 10, 1975, the Basel group proposed to name the absorption coefficients of any material on an arbitrary scale, 'Hounsfield Units' (HU). This was accepted enthusiastically by the audience. During this meeting G. N. Hounsfield and R. S. Ledley, physicist of Georgetown University in Washington, reported on new whole body scanners. The neuroradiologist G. Di Chiro from the National Institutes of Health, Maryland, compared the scanners and predicts: 'I cannot think that the structural representation of other parts of the body (fig. 5B) won't be as good as that in the brain. Anyway, the intellectual shock which the EMI-Scanner has given will continue to have an effect on us'. Louis Kreel at Northwick Park Hospital, Harrow, U.K., received Europe's first general-purpose EMI Whole-Body CT-Machine early in 1975[69]. After many other major awards the industrial engineer G. N. Hounsfield in 1975 had the distinction of an honorary doctorate from the Medical Faculty of Basel University, and in 1979 together with the South African physicist A. M. Cormack (born 1924) the Nobel Prize.

However some reservations about the new and expensive CT-technique continued for a time. So a short-term information session about the Basel studies at the sixty-first annual meeting of the Swiss Roentgen Society, June 22, 1974 in Gstaad, was introduced by the chairman with the words: 'There is a brief report on the new machine of prestige in Basel . . .'. Meanwhile the further development of CT with diverse possibilities of picture postprocessing went on. Unnecessary details can be faded out electronically and important traits emphasized or enlarged. With high-resolution scanning, millimetre-scale structures of the middle and inner ear can now be represented. Rapid spiral-CT units reconstruct all the body regions without superposition in continuous thin-slice technique. Fine pulmonary structures can be delineated as exactly as blood vessels during CM-injection in angio-CT or pictures, which can be converted into pseudo-3-dimensional (3D) representations. For detection of malignant tumours, specific angiological, trauma and orthopedic investigations, guided biopsies or minimally invasive presurgical and radiotherapeutical planning, CT has become a standard method of diagnostic imaging. It has replaced completely or partially other laborious and (for the patient) unpleasant examinations.

Diagnostic ultrasonography (US)

This objective acoustic tool of pattern recognition without radiation exposure has influenced medical diagnostic practice profoundly. Relatively inexpensive and accessible it is extensively used not only in medical centres but more generally. The high power US technology originates from the piezoelectric effect and the echo-impulse technique of submarine detection of World War I. Pierre Curie (1859–1906), later the husband of the famous Marie Curie-Sklodowska (1867–1934) (see Rösler in this issue), and his brother discovered the piezoelectric effect in 1880 while experimenting with crystals. The crystal converts electric pulses into vibrations that penetrate fluids very well. Sound waves, which are reflected back to the crystal from surfaces of objects like submarines or organs inside the body, are reconverted into electric signals. A computer translates the signals into images. Nearly 60 years later the Austrian neurologist K. T. Dussik with his brother, a physicist, and other investigators, recognized the applicability of high-frequency sound waves as a diagnostic procedure[25]. But this method and the equipment developed slowly. It only became a practical imaging tool in about 1970. Then its evolution accelerated by digital processing and storage of real-time imaging. Now optimum focusing at a chosen depth of several centimetres in the patient's body is a way of exploring abnormal anatomy instead of palpation and percussion. With the computer-aided US equipment, physicians got an electronic stethoscope. However some limitations of this physical tool must be kept in mind. US cannot see through bone, and air in lungs and bowel segments is a bad conductor of the mechanical waves in contrast to fluids. For certain indications – e.g. fetal controls in obstetrical-US, testing for gallstones, the evaluation of parenchymatous organs in tumorous diseases with needle guidance for biopsies of pathological tissue or of the volume and wall structures of hollow organs, etc. – US has become a further diagnostic method of great value. Most of the previously required CM-examinations of the gallbladder[9] have been replaced by the US detection of stones and pathological alterations of the wall. It is the same with the urinary bladder. Objects moving towards or away from a given point and their flow velocity are registrated by shifts in the frequency of US waves, the Doppler effect. The echoing sound detects an uneven blood flow through narrowed vessels or faulty cardial valves and blockages. In several cases of pathology and some regions of the body alterations can be identified better by CT or MR. So different methods are preferred in an individual situation. Therefore, used systematically, US, CT and MR complement each other very well. They are correlated to other scanning techniques and all are correlated with pathology.

Magnetic resonance (MR), an 'in vivo dialogue' with special atoms in the body

MR (or nuclear magnetic resonance, NMR) respresents the latest development in diagnostic imaging without radiation exposure. The physical principle applied by this method is again very different from conventional roentgenology, CT or US. In this method the magnetic momentum present in certain atomic nucleic, discovered by Otto Stern (1888–1969), Nobel laureate in 1943[79], is directly measured by means of nuclear magnetic resonance, developed by Isidor I. Rabi (1898–1988), Nobel prize-winner in 1944. Since 1946 the magnetic momenta of many atomic nuclei have been analysed by resonance methods. An almost incredible precision was achieved by Felix Bloch (1905–1983) from Zurich at Stanford University, California. Together with the physicist Edward Mills Purcell (born 1912) of Harvard University, Cambridge, USA, he received the Nobel prize in physics in 1952. Examinations in MR were further promoted at the Swiss Federal Institute of Technology (ETH) in Zurich between 1966 and 1975 by the physical chemist Richard R. Ernst (born 1933) of Winterthur (Switzerland), Nobel laureate in 1991[30,104], Raymond Damadian, New York, in 1971[16], and Paul C. Lauterbur, University of Illinois, in 1972/73[79].

The application of the MR method allows a real-time dialogue between the investigator and certain atomic nuclei in the patient's body by means of variation of radio waves in a strong magnetic field. With appropiate radiofrequency and pulse-length the investigator obtains MR-signals which are collected and processed to obtain images (fig. 6A, B). The strength of the applied magnetic field is in the range of 1.0 to 1.5 T (Tesla) (1 T = 10,000 G (Gauss), the earth's own magnetic field is about 0.5 G). This technique is called MR-tomography or MR-imaging (MRI) and represents a further revolution in medical imaging.

A second major application of MR-method, the MR-spectroscopy (MRS), complements imaging by topical MR recording of biochemical processes. This technique

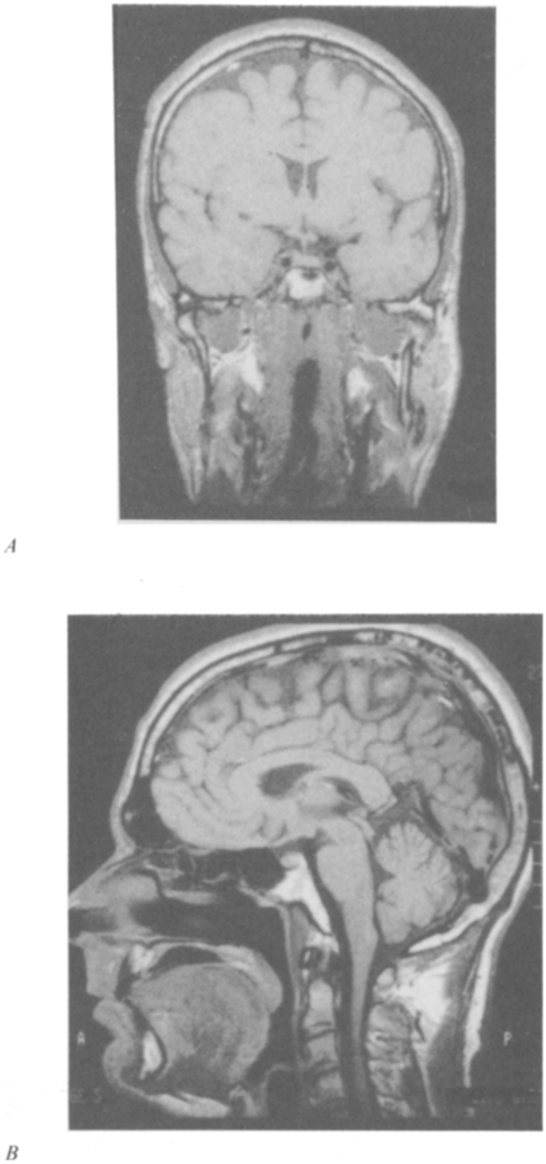


Figure 6. *A* MRI 1991. One reconstructed frontal section of the head with fine soft tissue structures.
B Same patient. Reconstructed midline section, lateral view.

features the recording of selective MR-spectra from individual organs or body parts and permits a qualitative tissue discrimination in the respective topical volume. MRI and MRS, both non-invasive, have great potential to relate soft tissue structures with local biochemistry in vivo. But before this technique can be used more effectively in clinical diagnosis a better understanding of the metabolites monitored is required and therefore is still a subject of research[79,92,104]. Tissue contrast can be enhanced by paramagnetic MR-CM[27].

Initiated by CT picture processing, multiplanar and 3D imaging can nowadays support preoperational planning. In the image, superimposed tissues interfering with a surgical intervention towards a pathological focus can be removed electronically. Thus surgeons, with the help of radiologists, can look for the optimal access to a pathological spot such as through a channel without, for instance, affecting vital organs. This kind of information is part of minimal-invasive preoperative planning.

Since 1978 image reconstruction in any plane with high contrast and soft tissue discrimination has been possible with prototypes of MR machines. In 1984 the first European congress in MRI was held and led to the formation of the European Society of Nuclear Magnetic Resonance In Medicine in Geneva. In 1991 more than 5,000 MR systems were running world-wide. As a powerful and sensitive diagnostic tool with an explosive growth, MRI and MRS have become exciting new ways to analyse anatomical, functional and biochemical changes in living human tissue. With fast and ultra-fast imaging-sequences MR can do certain things better than other imaging devices. For studies of the brain and spinal cord it has largely replaced CT. Other well-tried radiologic techniques like catheter-angiography will be replaced by tailored CT- or MRI-examinations step by step.

The new digitized diagnostic procedures with immediate data access connect several medical disciplines inside and outside hospitals. They require standards, data protection, permanent quality control, and good clinical practice. They also carry the danger of diagnostic overkill. Finally we face questions of medical ethics and cost-benefit relations.

Interventional radiology

Without attempting completeness, some methods of interventional radiology must be mentioned. They were developed over the last three decades. Transitions between diagnostic and therapeutic procedures are now fluent. They replace many time-consuming and expensive operations and have grown to such an extent that interventional medicine is now regarded as a discipline in its own right. Patients have much benefited from the enormous progress. Once more heated discussions are concerned with the question of who should perform such interventions. The answer is, those physicians, who have talent, knowledge, experience, a trained staff and support. Interventional radiology began in 1964 with percutaneous transluminal dilatations in atherosclerotic stenoses of peripheral arteries. Charles T. Dotter and Melvin P. Judkins of the University of Oregon introduced this method using coaxial catheters of increasing size[23], the so-named percutaneous transluminal angioplasty (PTA). Dotter's catheter therapy originates from an event which happened during a vascular investigation. There he suddenly realized that he had put the catheter through an atherosclerotic obstructed artery. In alarm he draw back the catheter. To his surprise the accidently pierced channel remained open and blood flowed through the vessel again. Initially the Dotter-

Judkins method did not prevail in its own country. It might have been forgotten, if Eberhard Zeitler (born 1930) and Werner Schoop (born 1924) had not continued with it in Germany[53,108]. Some years later at the medical outpatient department of the University Hospital in Zurich (Switzerland), Andreas Roland Grüntzig (1939–1985) from Germany modified and miniaturized the catheter systems and introduced a percutaneous technique for coronary PTA (PTCA) with a special balloon catheter system on September 16, 1977[43–45]. Without adequate support in Zurich, he went to the United States for further development of his method. In 1985 he died in a plane crash.

Other milestones of interventional radiology are laser-recanalizations of stenosed or obstructed vessels, selective transcatheter embolizations of tumours, small bleeding vessels and vascular malformations, and delivery of therapeutic agents to a distinct site. Furthermore implantations of balloon-expandable[83] or selfexpanding stents into stenosed or obstructed arteries or into non-operable, tumour-infiltrated and blocked ducts, such as biliary ducts in obstructive jaundice, reopens those channels for a time[53,75]. When stenting, the question is what mechanical and pathophysiological conditions exist and which stent is to be used? Despite this change of medical-technical panorama during the second half of this century we would not want to ignore the fact that even today 70 to 80% of all radiological achievements, even in economically developed countries, are due to the longstanding direct conventional Roentgen imaging (see fig. 1).

Quo vadis, diagnostic imaging?

It is hardly prophetic to say that the tremendous changes of the past 30 years will continue or will even be accelerated. Certainly powerful new microcomputers, highly sophisticated software packages for image reconstruction and processing as well as telecommunication networks for data exchange or teleoperations will take part in it.

Diagnostic imaging will be a central part of future diagnostics, therapy planning and research. It will become a more effective interdisciplinary research field with contacts in other disciplines of medicine and science. Image resolution will reach the molecular level. Step by step we will approach a more 'transparent human being'. The diagnostic ability to discriminate between benign and malignant processes will develop further. Increasing emphasis will be placed on organ morphology and function together with local in vivo biochemistry. Assigned digital and analogous information from different sources will be combined, leading to new information and thus diagnoses. In the future information scientists, engineers, physicists, biochemists as physicians of different disciplines must cooperate much more closely. These collaborations could be centralized, and not only for cost reasons, in imaging centres that are real-time connected for dialogue to peripheral satellites.

Research perspectives for the future demand more investment in education and postgraduate training on a high level. The virtual reality of computer graphics will enrich and facilitate it. The young generation will go further into detail in the field of imaging-diagnostics, starting from hard data and using computer models for decision making. But this, the artificial world of data, possesses a Janus face. It gives the illusion of nature, but which never reaches the complexity of reality. Physicians will have to differentiate between the human being and the computer model.

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