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Jian Wang
Xuening Zhang
Editors

Radiology of Infectious and Inflammatory Diseases - Volume 1

Brain and spinal cord

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Beijing

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Preface

With the rapid development of modern society and economy, people's lifestyles and population mobility have changed, and the impact of infectious and inflammatory diseases on human survival and socio-economic development has become increasingly significant. The National Health Commission has issued a document emphasizing the need to establish infectious disease departments and infection control offices in hospitals above the second level nationwide, placing unprecedented emphasis on the danger of infectious diseases to human health. In the past 30 years, the development of medical imaging diagnosis and treatment technology has greatly contributed to the change of modern diagnosis and treatment mode. The high reliance of modern medicine on medical imaging technology has given the medical imaging profession an important mission in the field of diagnosis and differential diagnosis of infectious and inflammatory diseases.

In the course of long-term clinical practice and scientific research, my team and I realized that it had seriously affected the quality of patient care and outcomes, caused the misuse of clinical antibiotics, affected patient health and quality of life, and increased the economic burden on families and society because of the neglect and lack of research on the construction of a key disciplinary system, systematic theoretical system, and standardized guidelines for infection and inflammation diseases. Based on the above considerations, this book brings together the Infectious Diseases Group of the Radiology Branch of the Chinese Medical Association, the Infection Imaging Committee of the Radiologists Branch of the Chinese Medical Association, the Infection and Inflammation Radiology Committee of the Chinese Society of Research Hospitals, the Infection (Infectious Diseases) Imaging Working Committee of the Chinese Association for STD and AIDS Prevention and Control, the Infectious Diseases Imaging Group of the Infectious Diseases Hospital Branch of the Chinese Hospital Association, and the Beijing Technological Innovation Alliance for Imaging and Treatment. The book summarizes the imaging features and evolution of infectious and inflammatory diseases, reveals the pathological basis of infectious and inflammatory diseases, and presents the key points of imaging diagnosis and differential diagnosis of infectious and inflammatory diseases. I believe that the publication of this set of books will promote the prevention and control of infection and inflammatory diseases, rational drug use and academic development of radiological imaging diagnosis in China, and effectively serve the precise clinical treatment.

This set of books provides the first systematic theoretical treatment of the subject of infection and inflammatory radiology. There are a total of six volumes, including a cranial spinal cord volume, a head and neck volume, a cardiothoracic volume, an abdominopelvic volume, a skeletal muscle volume, and a pediatric volume. The content covers the four major groups of pathogenic (bacterial, fungal, viral, parasitic) infections associated with infectious diseases and inflammatory diseases such as autoimmune diseases.

This series of books features three main advantages: (1) close to the clinical setting, with a complete range of diseases, covering common, frequent, and rare clinical infections and inflammatory diseases; (2) the information is comprehensive, which emphasizes the objective basis of diagnosis, especially the completeness, representativeness, continuity, and authenticity of cases and images; (3) most of the information comes from the editor's clinical experience and accumulation, and several parts of the information are authorized by international

colleagues, and the overall absorption and citation of the latest research results at home and abroad, as well as the layout and content of the books are innovative in nature.

For the successful publication of this set of books, we set up an advisory committee and an expert committee, with scientific design and systematic demonstration, and it took more than 1 year to design the outline and revise the manuscript. In addition to the Chinese version, Springer Publishing Group will publish the English version. The editorial committee attached great importance to the book and organized several training sessions for the editorial board members on writing standardization, explained the process of professional review and finalization, and assigned specialized personnel to organize review, revision, and supplementation. As the editor-in-chief of this book, I would like to express my sincere gratefulness for this. At the same time, I would like to express my sincere gratitude to the members of the national infectious disease imaging team who participated in the preparation of this book for their efforts.

In the face of the current critical situation in the prevention and treatment of infectious and inflammatory diseases, the publication of this monograph will serve as another powerful weapon in the war against infectious and inflammatory diseases, and will play an important role in improving the level of diagnosis and treatment of physicians, improving the quality of life of patients, and prolonging their lives.

The process of scientific development is also a process of gradual improvement of people's understanding, and deviations are inevitable, so I would appreciate your kind advice and look forward to its improvement!

Beijing, China
November 2019

Hongjun Li

Preface

As an "Old and Fashionable" topic, infectious diseases have been with human development since the era of plague and famine. In recent years, with the continued prevalence of diseases such as severe acute respiratory syndrome, avian influenza, and Ebola hemorrhagic fever, novel pathogens are being discovered and the spectrum of underlying diseases is being transformed and pathogen resistance has been increasing, and the risk of infectious diseases to humans continues to deteriorate. In the 1970s, some experts predicted that infectious diseases could be completely defeated in the near future, but now it seems that the cause of defeating infectious diseases is a long way off.

Being an emerging branch of the medical disease classification system, infectious and inflammatory diseases have seen various types of research flourish in various fields in recent years. Infectious diseases of the central nervous system are one of the common serious infectious diseases, and the diversity and complexity of their lesions make early diagnosis and accurate diagnosis very difficult, with rapid disease progression and high rates of death and sequelae. With the rapid development of imaging technology, medical imaging plays a pivotal role in the diagnosis of the disease, and its role in assessing the efficacy and prognosis cannot be ignored. At present, there are few monographs on nervous system infection, and the existing books in the field of imaging medicine are limited in their description of infectious and inflammatory diseases of the central nervous system, covering few diseases, inconsistent classification methods, and incomplete descriptions of new imaging techniques.

In this context, the book series "Infection and Inflammation Radiology" led by Prof. Li Hongjun from our infection imaging community was born. Radiology of Infection and Inflammation—Cranial, Cerebrospinal and Spinal Volumes is one of the volumes that takes care to draw on the proven national and international experience in recent years in infectious and inflammatory diseases of the central nervous system with due attention to clinical utility.

This book clearly differentiates the traditional classification of infectious and inflammatory diseases into those that are affiliated with infectious diseases and those that are not, clearly differentiating it from other similar books. Each disease in this book is described with a corresponding pathology, highlighting the contrast and causal relationship between pathology and imaging presentations. Each disease has individually distilled diagnostic points that are concise and easy to access. In addition, this book presents research advances in the imaging of infectious and inflammatory diseases of the central nervous system and discusses the value of a variety of new imaging techniques that are relatively well established in the diagnosis and differential diagnosis of various diseases or in guiding treatment and assessing prognosis, in conjunction with the most recent references.

With an excellent authoring team, this book is compiled by a number of renowned experts in the field of imaging of CNS infectious and inflammatory diseases in China, combining the latest domestic and international guidelines, research advances, and their own clinical practice experience. The book also brings together cases from more than a dozen large tertiary hospitals in China where these experts work, showing valuable images of multiple diseases, especially those of some rare diseases. It is a valuable reference book for imaging and other clinicians.

I would like to express my sincere gratitude to all the editorial board, the editorial staff, and colleagues who contributed cases to this book! With an eye to the current practical needs of the

general reader for clinical work and extended learning, this book is an informative, concise, easy-to-read, efficient, and practical reference on infection imaging. Due to limited conditions, some rare diseases lack typical pictures, and we hope that colleagues will criticize and correct any shortcomings in this book.

Urumqi, China
February 2020

Jian Wang

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About the Editors

Hongjun Li, MD Chief Physician, Professor, Doctoral Supervisor. He is currently the Director of the Medical Imaging Center of Beijing Youan Hospital, Capital Medical University, and Deputy Director of the Department of Medical Imaging of Capital Medical University. He is one of the first cohorts of "Ten Hundred Thousand" health professionals in Beijing, and one of the first cohorts of "215" high-level health professionals in Beijing. He is an editor-in-chief of *Radiology of Infectious Diseases*, associate editor of *BMC*. He is an associate editor of *Neurology*. He is the chairman of Infectious Diseases Group of Chinese Radiology Branch, the chairman of Infection Imaging Committee of Radiologists Branch of Chinese Physicians Association, the chairman of Infection and Inflammation Radiology Committee of Chinese Research Hospital Society, the chairman of Infection (Infectious Diseases) Imaging Working Committee of Chinese STD and AIDS Prevention and Control Association, and the chairman of Beijing Technology Innovation Alliance of Imaging Diagnosis and Treatment.

Dr. Li is mainly engaged in diagnostic imaging of infection and inflammation and has supervised more than 20 doctoral and master's students. In recent years, Dr. Li has conducted more than 10 research projects, including 1 major project of National Science and Technology, 1 key and 2 general programs of National Natural Science Foundation of China. He has edited 2 textbooks, 28 monographs in English and Chinese, and 3 translations of monographs, and the total number of downloads of English monographs has reached 160,000. He also edited *Radiology of HIV/AIDS* and *Radiology of Infectious Diseases 1–2*, which were awarded the "Outstanding Book Award for Publication" in 2014 and 2015 respectively, and the "General Award" by the State Administration of Press, Publication, Radio, Film and Television in 2017. He has published more than 200 papers, including more than 60 SCI articles. He has obtained 2 national invention patents and 16 intellectual property registrations. He received 9 provincial and ministerial awards, including the Chinese Medical Science and Technology Award. He was awarded the title of "Master Teacher and Apprentice" by the Beijing Municipal Federation of Trade Unions, and his research team was awarded the title of "Scientific and Technological Innovation Cultivation Team" by the Beijing Municipal Hospital Administration and "Municipal

Staff Innovation Studio" by the Beijing Municipal Federation of Trade Unions and Beijing Municipal Science and Technology Commission.

Jian Wang Deputy director of the Imaging Center of the First Affiliated Hospital of Xinjiang Medical University, Chief Physician, Professor, Doctoral Supervisor. She is the member of the Magnetic Resonance Imaging Group of the Radiology Branch of the Chinese Medical Association, member of the Neuroimaging Specialty Committee of the Radiologists Branch of the Chinese Medical Association, member of the Neurology Group of the Magnetic Resonance Imaging Specialty Committee of the Radiology Branch of the Chinese Medical Association, standing member of the Infection and Inflammation Radiology Specialty Committee of the Chinese Society of Research Hospitals, standing member of the Neurodegenerative Diseases Specialty Committee of the Chinese Society of Microcirculation, and standing member of the Magnetic Resonance Imaging Equipment and Technology Specialty Committee of the Chinese Medical Equipment Association. She is also the deputy director of the Infectious Disease Imaging Committee of Beijing Imaging and Diagnostic Technology Innovation Union, the executive member of Xinjiang Radiology Branch of Chinese Medical Association, the leader of Magnetic Resonance Group of Xinjiang Radiology Branch of Chinese Medical Association, the deputy director of Xinjiang Uygur Autonomous Region Diagnostic Radiology Quality Control Center, the member of Xinjiang Medical Association Medical Accident Technical Identification Expert Pool, the member of Xinjiang Uygur Autonomous Region Class B Large Medical Equipment Management Committee. She is also the member of the expert pool of medical equipment bidding expert pool of Xinjiang Uygur Autonomous Region Finance Department, and a natural science expert of Xinjiang. She is also an editorial board member of *Radiology of Infectious Diseases* and member of International Society for Magnetic Resonance in Medicine (ISMRM). Dr. Wang has received more than 10 grants from the National Natural Science Foundation of China and other scientific research funds, and won the second prize of the Science and Technology Progress Award of Xinjiang Uygur Autonomous Region (provincial level) in 2017. She has supervised 39 master's and PhD students (including 2 overseas students).

Xuening Zhang Chief of the Department of Medical Imaging, Second Hospital of Tianjin Medical University, Chief Physician, Professor, Doctoral Supervisor. She is a member of the Radiology Branch of the Chinese Medical Association, member of the Magnetic Resonance Committee of the Radiology Branch of the Chinese Medical. He is a member of the Radiology Branch of the Chinese Medical Association, and deputy director of the Magnetic Resonance Committee of the Radiology Branch of the Chinese Medical Association. She is also the member of the Standing Committee of the Radiology Committee of the China Healthcare International Exchange and Promotion Association, member of the Standing Committee

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Part I

General Introduction to Infectious and Inflammatory Diseases of the Central Nervous System

Introduction to Imaging Methods

1

Bailu Liu, Yuehua Li, Kai Shang, Jian Zhang, He Wang, Qianfeng Wang, Jiaying Tang, Yongde Qin, Xiaohong Li, and Xin Gao

Central nervous system infections remain relatively high in morbidity and mortality worldwide; many of the known pathogens that can cause infectious diseases include broad-spectrum bacteria, viruses, fungi, mycobacteria, and parasites. In 1971, Omran [1] proposed a theory of epidemiological transition in developing countries, describing the mortality changes and disease patterns of CNS infections in these countries, which consisted of three phases, namely, the "era of plague and famine," the "era of pandemics," and the "era of degeneration and human-made diseases." A recent annual mortality rate published in the United States and data from the World Health Organization reflect a decline in mortality associated with infectious diseases and a gradual evolution of infectious diseases to chronic diseases. CNS infection is common clinical serious infectious conditions, which are mainly meningitis and encephalitis syndrome, etc. CNS diseases such as intracranial tumor, cerebral hemorrhage, and craniocerebral trauma can be treated effectively by surgery, but the rate of postoperative infection is still on the rise. The progression of CNS infections is often very rapid in nature and is characterized by a high mortality rate and a high incidence of sequelae.

Multimodal medical imaging has played a prominent role in the diagnosis, treatment, follow-up, and assessment of prognosis of various CNS diseases. Present examinations used for CNS infectious diseases include cranial radiographs, computed tomography (CT), magnetic resonance imaging (MRI), nuclear imaging, and functional and molecular imaging, all of which have their own advantages and limitations. Innovative new imaging technologies have greatly expanded the applications of imaging in central nervous system diseases. This chapter focuses on the various imaging techniques of the central nervous system and advancements in new imaging techniques.

CNS infections and inflammatory diseases that are not diagnosed in a timely manner and given diagnostic treatment may lead to a certain mortality rate at times. When a suspected CNS infectious disease is encountered, imaging physicians who can provide relatively complete diagnostic and differential diagnostic information may offer clinicians objective information which is crucial to the treatment of the disease.

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1.1 X-Ray Imaging Techniques

Bailu Liu, Yuehua Li, and Kai Shang

1.1.1 X-Ray Imaging Principle

The X-ray image is an image formed directly by X-ray transmitted through the human body. It is a direct analog gray-scale image, consisting of images of different shades of gray

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from black to white, which reflects the anatomical and pathological conditions of human tissue and structures through the density of the image and its variations, which is mainly acquired by digital X-ray imaging equipment. There are three conditions that must be present for X-rays to be produced: (1) a population of freely moving electrons, (2) a high-voltage electric field that causes electrons to move at high speed under vacuum conditions, and (3) a target surface that prevents fast-moving electrons. Therefore, two essential pieces of equipment are necessary for X-ray imaging, namely, an X-ray bulb and a high-voltage generator. The penetration, fluorescence, and photoreceptor effects of X-rays are the basis for their application in diagnostic imaging. In addition, there are differences in the absorption of X-rays due to different densities of human tissues and different structures of pathological tissues, which result in a black and white contrasted image on the fluoroscope or photograph. The extent to which X-rays are absorbed through different tissues in the body and other substances can be influenced by the following factors: (1) the density of the substance, (2) the thickness of the substance, and (3) the wavelength of the X-ray.

1.1.2 X-Ray Imaging Method

Digital X-ray imaging equipment is an X-ray device that digitizes X-ray transmission images and processes them for conversion into analog images for display. Depending on the imaging mechanism, it can be divided into computed radiography (CR) devices and digitized radiography (DR) devices [2].

CR records X-ray images using an image plate (IP) and then converts the stored signal into an optical signal by laser scanning, and the optical signal is converted into an electrical signal by a photomultiplier tube, which is then input to a computer for processing by analog/digital (A/D) conversion to form a high-quality digital image. CR utilizes IP as a planar radiation detector, which mainly includes information acquisition, information conversion, information processing, information storage, and recording components:

1. Information acquisition: Instead of traditional film, IP is used to record X-ray images in the form of latent images. The X-ray photons injected into the IP are absorbed by the photo-stimulated luminescent (PSL) fluorescent material within the fluorescent layer, releasing electrons, some of which are scattered within the fluorescent material in a semi-stable state, forming the latent image. The semi-stable electrons are converted to fluorescence (PSL phenomenon) when the IP with latent image is scanned linearly with the laser beam, and the intensity of this fluorescence is proportional to the intensity of the X-rays at the time of the first excitation.
2. Information conversion: The conversion is realized by the image reading device, which completes the photoelectric conversion and A/D conversion of the fluorescent image, and finally converts it into a digital image signal.
3. Information processing: This is executed by computer, which performs various post-processing on digital images, such as enlargement, grayscale processing, subtraction processing, etc.
4. Information storage and recording: Laser printer film is the conventional way of recording. The CR image can also be displayed directly on the computer monitor.

Based on different detector structure types and imaging technologies, DR can be divided into direct digital X-ray imaging (amorphous selenium), indirect digital X-ray imaging (amorphous silicon), CCD X-ray imaging, and multiwire proportional chamber (MWPC) imaging. Amorphous selenium and amorphous silicon are presently mostly used for imaging [3]. The X-ray photons will react with cesium iodide (CsI) to generate fluorescence when they pass through the amorphous silicon flat panel detector. These fluorescent photons will be converted into the corresponding electrical signals by the photodiode. Studies have shown that the quantum capture efficiency of amorphous silicon flat panel detectors is significantly improved, which means that the X-ray dose can be significantly reduced without compromising image quality. The X-ray will interact with the amorphous selenium semiconductor to produce positive and negative electron pairs when they pass through the amorphous selenium detector, generating the corresponding electrical signals. The process does not involve significant information conversion with minimal information loss while obtaining clear, high-quality images.

The emergence of digital X-ray devices such as CR and DR has replaced traditional film, which can be connected to the picture archiving and communication system (PACS) for sharing over the network; facilitating storage, transmission, and remote diagnosis; and contributing to the development of teleradiology. DR devices have higher spatial resolution and signal-to-noise ratio than CR devices [4], have shorter imaging times, and require lower X-ray doses, but CR devices are less expensive and can be used in conjunction with original X-ray machines. Both devices have advantages over conventional screen-and-slice photography in terms of X-ray dose, image resolution, and post-processing.

1.1.3 X-Ray Imaging Methods Commonly Used in the Brain and Spinal Cord

A cranial X-ray is the most commonly used X radiographic method for craniospinal imaging. Anterior-posterior and lateral view is commonly used, while axial, tangential, and

mento-vertical view may sometimes be used as needed. The anterior-posterior view shows images of symmetrical shape and size of the two orbits, with the outer edges of the two orbits shown equidistant from the outer edge of the skull. The skull is properly laid out in the X-ray radiograph, and the image quality is considered satisfactory when the petrosa does not overlap with the supraorbital rim. The lateral view of the skull clearly shows the edge of the sella turcica, and the image quality is considered satisfactory when the anterior-posterior pterygoid process overlaps without bilateral display. The axial view is used to present a symmetrical skull base image of the ambilateral petrous bone and zygomatic bone. The image quality is satisfied when the mandible's coronoid process is equidistant from the outer edge of the skull on both sides, the inferior dentition overlaps with the interbrow, the odontoid process is anterior to the middle of the foramen magnum of the occipital bone but does not overlap with the anterior edge of the atlas, and the foramen ovale and foramen spinosum of the middle cranial fossa are clearly displayed. The mento-vertical position (skull base position) allows observation of the skull base; the frontal-occipital position (Towne's) shows the occipital bone, petrosal bone, and internal auditory canal; the orbital position visualizes the orbit, supraorbital fissure, and wings of sphenoid bone; the 45° axio-anterior oblique posterior (Stenver's) view visualizes the petrosal bone, internal auditory canal, and inner ear structures; and the local tangential view reveals details of the local skull. In addition, tomography can be used to detect bone and calcium plaques at the base of the skull; stereography can be used to detect intracranial calcium plaques or foreign bodies in relation to the spatial location of the cranial cavity; and magnification photography can show details of local bone structures.

The cranial X-ray radiographs usually could not provide a definitive diagnosis for infectious diseases of the central nervous system, but only indirect signs suggest intracranial lesions without specificity, for instance, intracranial septic infections and intracranial tuberculosis may show intracranial hypertension, mainly with widening of the cranial suture, increased pressure traces in the cerebral gyrus, bone resorption in the sella turcica, and enlargement and deformation of the sella turcica. Further CT and MRI should be performed when the cranial X-ray radiographs suggest abnormalities.

Pneumoencephalography, ventriculography and cisternography were once commonly used to diagnose cranial diseases; however, they have been abandoned as they are invasive techniques that can cause serious complications such as intracranial infection, intracranial hemorrhage, and cerebral edema.

1.2 CT Imaging Techniques

Yuehua Li, Jian Zhang, and Kai Shang

1.2.1 CT Imaging Principle

CT is the acronym for computed tomography. CT images are digitally converted reconstructed analog images, which are composed of a certain number of pixels of different gray scale from black to white aligned in an intrinsic matrix. The gray scale of the pixel reflects the X-ray absorption coefficient of the corresponding voxel. The basic imaging process is as follows: The X-ray is first emitted from the X-ray bulb, which is adjusted into an X-ray beam by the collimator and then penetrates a section of the human body before reaching the detector, where it is received and A/D converted to obtain an X-ray absorption profile of that section of the human body in a certain direction. This information is then stored in the computer, and the X-ray tube is rotated around the section to obtain a 360° X-ray absorption profile. This data is also input into the computer, and the display processor performs an inverse projection or analytical calculation of the absorption profile data in each direction to obtain the X-ray absorption values of the voxels at each spatial location within the section. These data are matrixed by spatial coordinates and displayed on the monitor in different resolution gray scales to obtain an anatomical image of the human section. The CT image also reflects the degree of absorption of X-ray by organs and tissues in gray scale. Where black shadows indicate low-absorption areas, i.e., low-density areas, such as lung tissue containing air, gray shadows indicate moderate-absorption areas, i.e., medium-density areas, such as muscles or organs of soft tissue, and white shadows indicate high-absorption areas, i.e., high-density areas, such as bone tissue containing high amounts of calcium. CT images have relatively high-density resolution and can be used for quantitative density analysis. In order to achieve the most optimal display of the tissue structures and lesions to be observed on CT images, it is necessary to employ different windowing techniques according to their range of CT values, which mainly include window level and window width [5]. The window width (W) is the range of the gray scale being displayed, and its middle value is called the window level (C). By increasing the window level, the image displayed on the fluorescent screen becomes black; by decreasing the window level, the image turns white. By increasing the window width, the number of layers on the image increases and the

contrast between tissues decreases; by decreasing the window width, the number of layers on the image decreases and the contrast between tissues increases.

1.2.2 CT Imaging Post-processing Techniques

The CT image is a tomographic image and can be subjected to various post-processing. CT image post-processing techniques involve a variety of 2D display techniques, 3D display techniques, and a multitude of other techniques for analysis, processing, and display. The two-dimensional display technologies consist of multiplanar reformation (MPR) and curved planar reformation (CPR); three-dimensional display technologies include volume rendering (VR), maximum intensity projection (MIP), minimum intensity projection (minIP), etc. The development and application of these analytical display techniques has greatly expanded the application areas of CT and significantly increased its diagnostic value.

1.2.3 CT Imaging Methods Commonly Used in the Brain and Spinal Cord

CT examination provides high diagnostic power for central nervous system diseases and has been commonly used. However, CT examinations use X-rays, and the radiation dose is significantly higher than that of conventional X-rays, which to a certain extent limits the application of CT, especially for the detection of specific lesions in obstetrics and gynecology and pediatric patients. In addition, there are still limitations in the etiologic diagnosis of disease with CT.

1. *CT plain scan and contrast-enhanced scan*. CT plain scan is a CT examination without contrast (an iodine agent which is impervious to X-ray), while CT contrast-enhanced scan is performed with intravenous injection of contrast to improve the contrast between the layers of tissue, thereby increasing the resolution of the CT examination.

   CT plain scan can show the location and extent of brain parenchymal lesions in CNS infection and inflammatory diseases and promptly detect the presence of edema, calcification, hemorrhage, and changes in the cerebrospinal fluid circulation system in the lesion area; enhanced scan is effective in showing the condition of endyma, blood-brain barrier, meningeal lesions, envelope of brain abscess, etc. A larger dose of enhanced scan is more helpful to visualize some small lesions. In some cases of CNS infectious diseases, CT scan is usually negative on the first to third day of onset, whereas enhanced scan can improve the detection rate of lesions, facilitate early diagnosis and treatment, improve clinical symptoms, and reduce mortality [6]. Therefore, enhanced CT scan should be performed promptly if there is a high suspicion of intracranial infection, and CT review should be performed in the recent future. However, for some patients with intracranial infections, there is the phenomenon of different diseases with mimicking images, and their CT findings are relatively similar, which cannot determine the specific pathogen by CT examination alone and requires analysis and comparison with other imaging examinations, laboratory tests, and clinical features to continuously improve the diagnostic accuracy. Figure 1.1 shows a patient with a brain abscess in which the CT scan image shows only a slightly hypodense foci next to the right lateral ventricle, and the extent of the lesion is blurred, while the boundary and extent of the lesion can be clearly shown after enhancement.
2. *CT angiography (CTA). CTA* is a noninvasive vascular imaging technique, the basic principle of which is to inject contrast agent through a vein, and the original tomographic image can be obtained by rapid scanning with multilayer spiral CT when the concentration of contrast agent in the target vessel reaches a threshold, and the three-dimensional structure of the vessel can be displayed by post-processing techniques such as VR and MIP. CTA is safe, convenient, and rapid for the diagnosis of cerebrovascular lesions. It also characterizes and locates the lesion and can be used as a screening method for cerebrovascular diseases such as cerebral aneurysms. Some people may experience adverse reactions to contrast agents, including facial flushing, headache, nausea, vomiting, hives, and conjunctival congestion in mild cases, or respiratory distress, unconsciousness, shock, cardiac arrhythmia, or cardiac arrest in severe cases, which require immediate emergency measures such as tracheotomy and cardiopulmonary resuscitation. CTA and magnetic resonance angiography (MRA) are primarily used to show the structure and course of arteries, while CT venous angiography and magnetic resonance venous angiography are more effective in the venous phase.

   There are four main techniques for cranial CTA, namely, general CTA, digital subtraction CTA, dual-energy CTA, and time-resolved CTA.

   (a) Conventional CTA: The basic principle is to inject contrast intravenously and acquire continuous volume during the peak filling period of the target vessel using spiral CT and then reconstruct the image of the target vessel in 2D or 3D or even 4D by using the post-processing function of computer. The conventional CTA in the general sense is a non-debridement CTA technique, which is more difficult to visualize lesions in the skull base segment of the internal carotid artery due to the overlapping of the skull base bones.

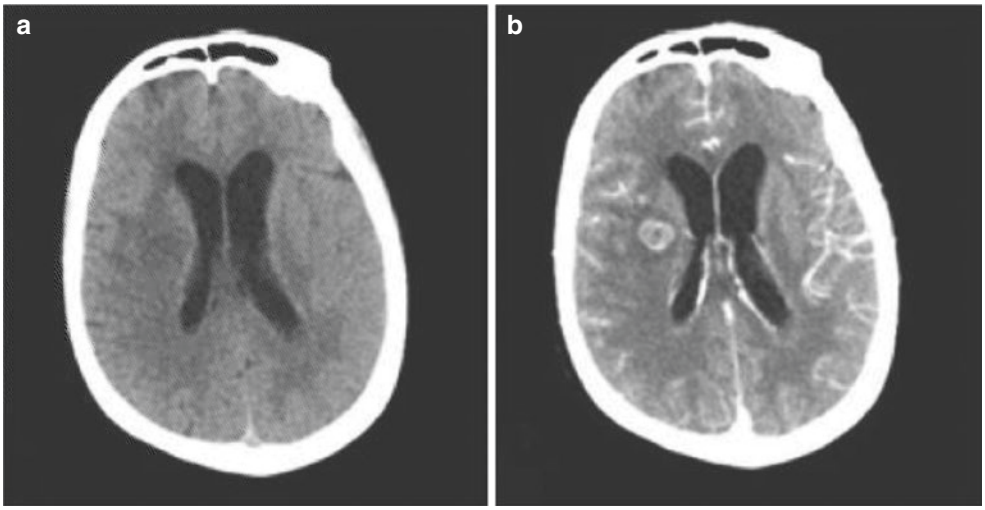

Fig. 1.1 Right paraventricular brain abscess. (**a**) CT plain scan shows a slightly hypodense lesion next to the right lateral ventricle, with slight compression of the right lateral ventricle; (**b**) enhanced CT can demonstrate the location, extent, and enhancement of the lesion more clearly

(b) Digital subtraction CTA: It is an automated bone subtraction CTA, which can better display lesions in the skull base segment of the internal carotid artery and improve the detection rate of internal carotid aneurysms in the skull base segment. Digital subtraction CTA uses the principles of digital subtraction angiography (DSA) to perform phase subtraction after two volume scans of plain and enhanced, and the subtracted data obtained is reconstructed in different ways to show the anatomy and lesions of the target vessels. Commonly used post-processing methods are VR, MIP, and MRP. VR takes different peaks of the pixel density histogram in the scanned volume to represent different tissues and then calculates on different tissue percentages for each pixel and converts them into different gray scales, displaying all sorts of structures in the volume in three dimensions with different gray scales and different transparency, which observes the vascular situation primarily through three dimensions. MIP is to superimpose the scanned 3D data and project the highest density voxels in the 3D data into the 2D data at the angle selected by the operator as the projection direction, and the remaining voxels are deleted in that projection direction. MIP can be projected from any angle, mainly to observe vascular calcification. MPR is a process of tomographic image reconstruction in any direction using three-dimensional reconstruction technique for data obtained from CT sampling, including planar reconstruction and curved surface reformation, which is mainly used to observe the relationship between the vicinity of blood vessels and to display tortuous vessels on the image. The technique is now routinely applied in clinical settings.

It should be noted that this technique requires that the bulb exposure angles should remain synchronized during the two subvolume scans. Low-tube voltage and low-tube current techniques should be used in plain scan to reduce the radiation dose received by the patient. Although radiation dose reduction measures have been used in the plain scan, it still increases the radiation dose received by the patient to some extent because of the requirement for two volumetric scans, plain and enhanced. Poor image alignment can occur in critically ill or poorly coordinated patients, where post-processing of the image is necessary with enhanced volumetric CT data, and this process is similar with the conventional CTA. During the digital subtraction CTA scan, the patient should be advised not to swallow and to remain still during the examination and to remove any metal ornaments from the head to avoid artifacts. The image quality is also related to the injection velocity of the autoinjector, which generally reaches 4.5–5.0 ml/s to obtain high-quality cranial CTA images. However, in elderly patients with poor vascular elasticity, high injection speed may cause leakage of contrast agent outside the blood vessels, and therefore it is often necessary to reduce the injection speed appropriately. Figure 1.2 shows a set of images obtained after digital subtraction CTA post-processing of the head and neck vessels.

(c) Dual-energy CTA: It is a method to remove bony structures (including vascular hard plaques) based on the difference in X-ray attenuation rates between the iodine component and the calcified or bony component of blood at different energy X-rays, whereby blood vessels in complex structures can be directly separated using dual-energy mode scanning and algorithmic processing. Presently, the dual-source and dual-energy CT technology is more than sophisticated. This technique allows for the acquisition of a

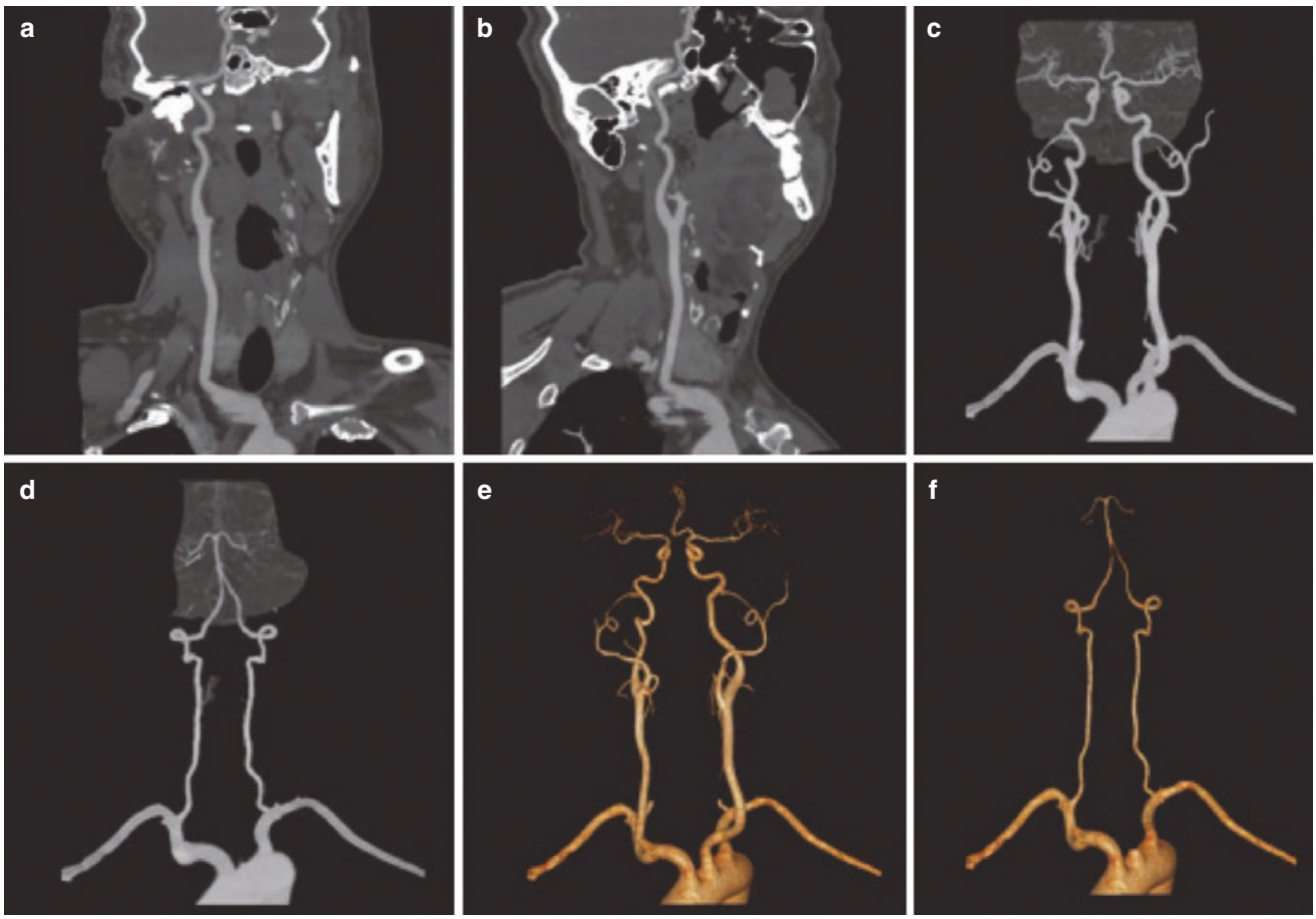

Fig. 1.2 Display of head and neck vessels by different CT post-processing techniques. (**a**, **b**) Curved surface reformation images of the head and neck arteries; (**c**, **d**) maximum density projection images of the intracranial anterior and posterior circulation; (**e**, **f**) volume reproduction images of the intracranial anterior and posterior circulation with bone removed

bone-depleted CTA image and a virtual cranial scan image to meet diagnostic needs with only one dual-energy enhanced CT scan and special dual-energy post-processing software, reducing the radiation dose to the patient and reducing the probability of poor image alignment. It has the same high diagnostic accuracy as digital subtraction CTA in the diagnosis of intracranial aneurysms.

(d) Time-resolved CTA: It is the technique of acquiring volumetric data of target vessels using multilayer spiral CT perfusion imaging, and then reconstructing the image with dynamic three-dimensional effect by post-processing software. It can be used not only for 3D imaging of cerebral vessels but also for providing functional parameters such as morphological changes of target vessels, which is a further expansion of the conventional concept of CT perfusion imaging technology and is mainly used for the diagnosis of cerebral ischemic lesions and vascular malformations.

3. *Energy spectrum CT* is a CT that uses the different absorption attenuation coefficients produced by substances at different energy X-rays to provide more image information than conventional CT. It has changed the conventional CT imaging method in which a single CT value is the standard and achieved high-resolution and high-definition images at ultralow doses, which has greatly improved CT imaging technology. The energy spectrum CT can conduct single-energy imaging, energy spectrum curve analysis, material separation and quantitative analysis, and effective atomic number calculation.

(a) Single-energy imaging: The energy spectrum CT can acquire 101 single-energy images in the range of 40–140 keV by the single-bulb dual-energy instantaneous switching isotropic acquisition technique, which is clearly different from the conventional CT using mixed-energy radiography. The corresponding CT values are obtained by calculating the absorption attenuation coefficients of the X-rays for different energies of the tissue, and thus the corresponding energy spectrum curves can be obtained. The differences in the energy profiles between substances are more pronounced in the lower-energy bands, and the

corresponding differences in the CT values are the largest. The best single-energy image can be obtained when the target tissue has the greatest difference in attenuation from the adjacent parenchymal organs at a certain energy level with minimal image noise, which is the optimal kiloelectron volt (keV) value for imaging that tissue. The image quality, signal-to-noise ratio, and contrast-to-noise ratio of single-energy images are superior to those of conventional CT and can also significantly reduce metallic artifacts, hardening artifacts of high-density contrast agents, hardening artifacts of dense bone edges, etc.

(b) Energy spectrum curve analysis: Substances exhibit different absorption and attenuation abilities with the change of X-ray energy, which enables to obtain the characteristic energy spectrum curve of a substance. The different energy spectrum curves suggest variations in their histological structures and pathological types.

(c) Substance separation and quantitative analysis: The photoelectric effect and the Compton effect produced by X-rays passing through substances collectively determine the attenuation curve of the substance, while any substance has its own specific attenuation curve. The attenuation curves of the substances are linear, and two substances can be selected as substrates; the spatial distribution and density of the target substance can be calculated by converting one substance into the density of two substrates that produce the same attenuation, and then the spatial distribution and density of the target substance can be calculated based on the known attenuation coefficients of the substrates, thus realizing the separation and quantitative analysis of the substance. It is important to note that substance composition analysis is not determining the substance composition but rather producing the same attenuation effect by the given two substrates. Consequently, the substrates chosen for the separation of substances are not static, but the most used are aqueous and iodine with different attenuation coefficients.

(d) Effective atomic number calculation: Every substance has a characteristic attenuation curve. The atomic number of an element is the effective atomic number of a substance when the X-ray absorption coefficient of that element is the same as the absorption attenuation coefficient of that substance, which can be used clinically for substance detection and identification.

The energy spectrum CT has outstanding advantages in angiography. Conventional CTA with mixed-energy X-ray has been found to be less effective in showing small arteries with a diameter of 1.5–3.0 mm due to sclerotic beam artifacts and a lower signal-to-noise ratio. However, energy spectrum CT allows scanning with lower-energy single-energy X-rays, which reduces sclerotic beam artifacts and increases contrast between tissues, highlighting small blood supply arteries injected with iodine-containing contrast agents and improving image quality. Meanwhile, the optimal single-energy imaging technique of energy spectrum CT can control the image noise in the proper range, further optimizing the display of small blood supply arteries of the lesion.

The energy spectrum scan requires high tube voltage, and the bulb is prone to overheat, which makes the energy spectrum scan unsuitable for a longtime, wide-range, and small-pitch uninterrupted scanning for the protection of the tube. In addition, the amount of data obtained from the energy spectrum scan is about five times larger than that of conventional CT, which takes a longer time for reading and post-processing of the images [7–9].

1.3 MRI Imaging Techniques

He Wang, Qianfeng Wang, and Jiaying Tang

1.3.1 Basic Principles and Image Characteristics of MR

The MR image, like CT image, is a digitally simulated grayscale image that can be displayed using windowing techniques and is capable of various image post-processing. However, the gray scale on MR images does not indicate the density of the tissue and lesion but rather represents the MR signal intensity, reflecting the length of the relaxation time and the magnitude of the proton density, which differs from CT.

Compared to CT examinations, which provide single density parameter imaging, MRI examinations can provide multiparameter imaging, such as T_1 values reflecting T_1 relaxation time and T_2 values reflecting T_2 relaxation time. Imaging that primarily reflects the difference in T_1 values between tissues is referred to as T_1-weighted imaging (T_1WI). Imaging that primarily reflects the difference in T_2 values between tissues is referred to as T_2-weighted imaging (T_2WI). Imaging that primarily reflects the difference in proton density between tissues is termed proton density-weighted imaging (PDWI). Cranial tissues and their lesions have different T_1 values, T_2 values, and proton densities, so T_1WI, T_2WI, and PDWI produce different signal intensities, which are manifested as different grayscale values. MRI examinations provide a diagnosis of craniocerebral diseases based on these grayscale changes. In general, the stronger the tissue signal, the brighter the corresponding part of the image; the weaker the tissue signal, the darker the corresponding part of the image.

However, it should be noted that the relationship between the length of the relaxation time T_1 and T_2 values and the signal intensity differs on T_1WI and T_2WI images. Short T_1 values are high signal, such as fat tissue; long T_1 values are low signal, such as cerebrospinal fluid; short T_2 values are low signal, such as bone cortex; and long T_2 values are high signal, such as cerebrospinal fluid. MRI examinations can also be performed by administering an intravenous contrast agent to artificially alter the contrast between the T_1 or T_2 values of the tissue and the lesion, in other words, the signal intensity of the T_1WI, or T_2WI images, to facilitate the detection and diagnosis of the lesion.

MRI examinations can be performed in multiple sequences, of which the most commonly used are spin echo (SE) sequences for T_1WI; turbo SE (TSE) or fast SE (FSE) sequences for T_2WI and PDWI and gradient echo (GRE) sequences are mainly used to acquire T_1WI, and T_2^*WI; inversion recovery (IR) sequences include short-time IR sequences for fat suppression and long-time IR sequences for free water suppression, i.e., fluid-attenuated inversion recovery (FLAIR) sequences; echo planar imaging (EPI) sequences are a fast imaging sequence mainly used for diffusion-weighted imaging (DWI), perfusion-weighted imaging (PWI), and functional imaging.

MR also allows for multidirectional tomography. In the clinical application of cranial diseases, MRI examinations routinely acquire axial, coronal, and sagittal tomographic images. Sometimes tomography of the inclined plane can also be performed according to diagnostic needs. The combination of multidirectional images can clearly demonstrate the anatomical relationship of tissue structures and help to clarify the origin and extent of the lesion.

Another outstanding advantage of MR images in terms of high soft tissue resolution is to facilitate the identification of normal structures and tissue types of lesions. In addition, some specific imaging sequences and imaging methods facilitate further confirmation of the histological features of the lesion. For example, subacute hemorrhage and fat tissue present similar hyperintense on T_1WI and T_2WI; however, when frequency-selective fat suppression technique is applied, the fat tissue is suppressed to low signal, while subacute hemorrhage remains high signal. Another example is that calcification and hemosiderin both present hypointense on T_2WI, which is difficult to distinguish from each other, but can be differentiated by applying GRE sequences or susceptibility weighted imaging (SWI), which show different signal intensities due to their different magnetization rates. The different imaging sequences and methods of MRI can facilitate the identification and diagnosis of lesions by accurately identifying the different histological types of normal structures and lesions.

In addition, MRI enables a variety of specific structural and functional imaging, which can reflect information on structural and functional aspects of the brain and structural and functional changes resulting from lesions. These special imaging methods include cerebral angiography, DWI, diffusion tensor imaging (DTI), PWI, magnetic resonance spectroscopy (MRS), SWI, and functional magnetic resonance imaging (fMRI).

1.3.2 Commonly Used MR Examinations for Infectious and Inflammatory Diseases of the Brain and Spinal Cord

1. *MRI plain and enhanced scans*: MRI plain scan is performed for patients without contrast injection. Presently, the majority of routine clinical examinations are MRI plain scans. However, when there is a large overlap between the relaxation times of normal and abnormal tissues, the MR signal of the lesioned tissue is similar to that of the normal tissue, and the lesioned tissue cannot be effectively distinguished on plain scan, or when the lesion can be detected on plain scan but the edges and internal structures of the lesioned tissue are not well visualized, it is necessary to inject contrast agent for the patient to increase the contrast, which is enhanced MR scan.

   Enhanced MR scan can help detect lesions that cannot be identified on plain scan and have an important role in the examination of many diseases. When contrast agent is injected intravenously into the patient, the distribution concentration of contrast agent varies among different tissues, and the contrast agent also affects the relaxation time of the tissues, which makes the difference between the images of normal and diseased tissues more pronounced and makes it easy to distinguish the lesions from the normal tissues. As an example, gadolinium-based contrast agents are the most widely used MRI contrast agents in clinical practice due to their strong paramagnetic effect. Gadolinium-based contrast agents achieve signal enhancement by altering the microenvironment of the lesion area, shortening the T_1 relaxation time, and accentuating the high signal on the T_1WI image.
2. *MRA*: Refers to a magnetic resonance imaging technique that uses the characteristics of blood flow to contrast the MR signal difference between blood flow and surrounding relatively stationary tissue [10]. MRA is widely used for clinical measurement of blood flow velocity, examination of lesions in blood vessels and surrounding tissues, etc., and is generally imaged using the GRE sequence. The MRA can be divided into two main categories, black blood and bright blood, based on the black and white of the blood displayed. Bright blood techniques can be fur-

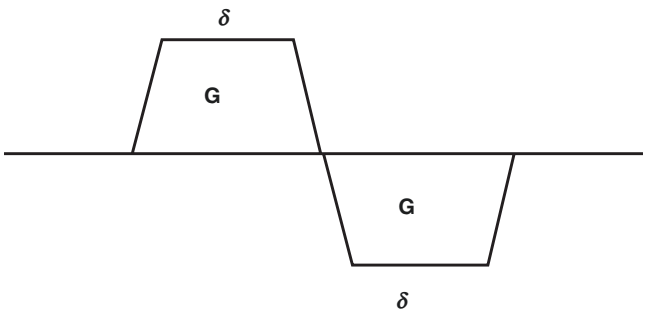

Fig. 1.3 Symmetric gradients applied in PCA imaging. *G* represents the gradient strength; *δ* represents the length of the gradient

ther divided into those with and without contrast enhancement [11].

The common methods of bright blood MRA examination are time-of-flight (TOF) and phase-contrast angiography (PCA) [12]. TOF is the most commonly used non-enhanced angiography method, which primarily utilizes RF pulses to saturate the tissues at the imaging site. These tissues appear as hypointense on the image because they are saturated, while the blood inside the vessel flows into the imaging site due to its flow characteristics, so that the blood inside the vessel appears as hyperintense on the image, thus enabling the differentiation between the vessel and the surrounding tissues. Two-dimensional TOF and three-dimensional TOF are commonly used in clinical practice. Two-dimensional TOF has a wide range of applications in angiography at sites where the direction of blood flow is perpendicular to the imaging plane, such as carotid arteries and peripheral vessels. Three-dimensional TOF is widely used in intracranial vascular imaging because of its ability to obtain high signal-to-noise ratio and spatial resolution.

PCA is achieved by applying two symmetrical gradients to the imaging site (Fig. 1.3; the gradients have the same amplitude and duration and opposite polarity). For stationary tissues, the positive and negative gradients produce equal scattering and regrouping phases, and their total phase change is zero; for flowing tissues, the positive and negative gradients produce a nonzero phase change due to their flow effects, so that the vessels and stationary tissues produce phase contrast. The strength of the phase is proportional to the velocity of blood flow in the vessel, and the direction of blood flow can also be determined from the positive and negative phases.

Balanced steady-state free precession (bSSFP)-MRA is another contrast-free angiography [13], in which the image contrast is determined by T_2/T_1 value. BSSFP sequence keeps the corresponding balance in each gradient direction, reduces the signal loss caused by blood flow, and can image in any blood flow direction. On bSSFP-MRA images, the arteries and veins both show hyperintensity, which is suitable for the imaging of thoracic aorta and coronary artery.

Black blood MRA suppresses the blood signal flowing in the blood vessel and retains the signal of surrounding static tissue, so that the blood on the blood vessel image displays hypointensity. The black blood signal can be achieved by accelerating the flow dispersion phase (fast spin echo sequence) or according to the T_1 value and T_2 value of blood and tissue (inversion recovery sequence).

Bright blood MRA can be divided into contrast-enhanced angiography and non-contrast-enhanced angiography. Arterial spin labeling (ASL)-MRA, bSSFP-MRA, TOF, and PC are all contrast-free-enhanced angiography [14].

Contrast-enhanced MR angiography (CE-MRA) is performed by high-pressure injection of a contrast-enhancing agent (e.g., gadolinium preparation), which is used to shorten the T_1 and T_2 relaxation times of the blood, thereby revealing the vasculature of the diseased tissue [15]. The advantages of CE-MRA over contrast-free MRA (e.g., time-of-flight and phase-contrast methods) are shorter acquisition times, improved imaging range, and reduced magnetization rate artifacts caused by blood flow and pulsation.

Magnetic resonance venography (MRV) refers to the technique of imaging the veins, which is usually performed using contrast injection or phase contrast. MRV is an important method for evaluating the intracranial venous system and diseases [16].

3. *Structural MRI*: It refers to the structural image that is scanned at high resolution in MRI, usually three-dimensional high-resolution T_1WI. Taking structural images of the human brain as an example, on the one hand, structural images have good gray-white matter contrast, which can be used to examine abnormal changes in tissue structure and even to quantify the volume of white or gray matter in specific brain regions; on the other hand, the clear gray-white matter contrast of structural images of the brain can be used to provide accurate localization for subsequent examinations, such as the positioning of the spectrum of the scan and the alignment of the anterior-posterior association during functional image scanning. In addition, structural images can be useful for post-processing of data, e.g., in functional brain data analysis, structural images are used to segment and align to stan-

dard brain templates, enabling more accurate alignment and analysis of functional images.

1.4 DSA Imaging Technique

Yuehua Li, Jian Zhang, and Kai Shang

1.4.1 Principle of DSA Imaging

DSA is a new examination method that combines computer and conventional X-ray angiography and was first developed by the Mistretta group at the University of Wisconsin and the Nadelman group at the University of Arizona in the 1980s. The basic content of subtraction technique is to subtract two frames of the same part of the human body, so as to obtain their difference part; the image without contrast agent is called mask image or mask, and the image obtained after injecting contrast agent is called contrast image or filled image. The image signal following subtraction is correlated with the absorption coefficient of the contrast agent and blood vessels, proportional to the thickness of the contrast agent and independent of the background. In subtracted images, background images such as bones and soft tissues are eliminated, leaving only images of blood vessels containing contrast (Fig. 1.4) [17].

The DSA imaging system consists of five components by function and structure: (1) X-ray machine with stable radiation quality; (2) fast image processing device; (3) X-ray positioning system and frame; (4) system control component; and (5) external equipment such as image display, storage, and network transmission component.

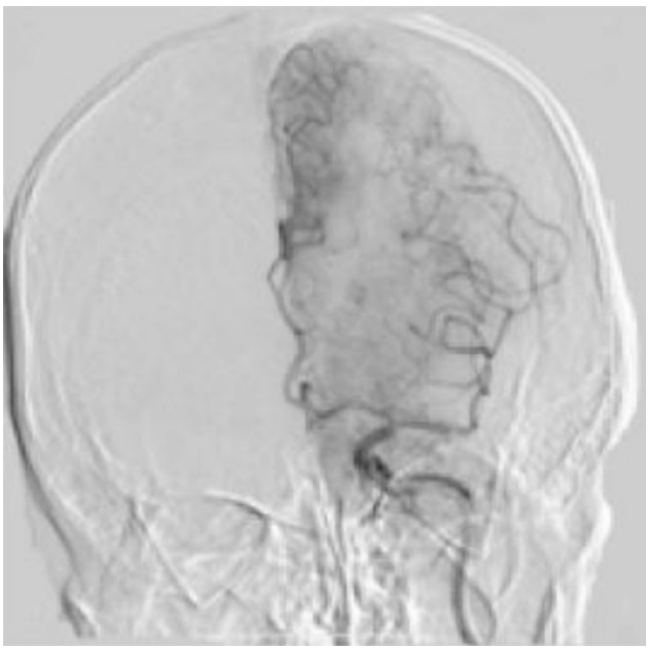

Fig. 1.4 Cranial DSA examination technique. Left internal carotid artery angiography

1.4.2 DSA Imaging Methods Commonly Used for Infectious and Inflammatory Diseases of the Brain and Spinal Cord

1. *The pulsed image mode*: Utilizes intermittent X-ray pulses to acquire the mask image when the contrast agent is not flowing into the vessel of interest, and the X-ray image is acquired and subtracted during the process of gradual diffusion of the contrast agent to obtain a series of continuous and interval subtracted images, with a large interval between each subtracted image frame and a high signal-to-noise ratio of the acquired images which are suitable for such areas as cerebral vessels, carotid arteries, hepatic arteries, and arteries of the extremities where the activity is slow.
2. *The super-pulsed method*: It performs X-ray pulse photography at a rate of 6–30 frames/s, followed by high-speed repeated subtraction frame by frame, enabling continuous observation of X-ray digital images or subtracted images at the speed of real-time video, with high dynamic clarity. It is suitable for fast-moving parts such as pulmonary arteries, coronary arteries, and heart.
3. *The continuous image mode*: The X-ray used can be either continuous or pulsed X-rays, obtaining a continuous image with a frequency of 25 or 30 frames/s synchronized with the camera, showing fast-moving parts with high temporal resolution.

With the development of technology, DSA systems also feature some specialized functions, such as rotational DSA, three-dimensional DSA, real-time smoothed mask (RSM) DSA, etc. Rotational DSA is an examination method to achieve dynamic observation by injecting contrast agent for exposure acquisition during the rotation of the C-arm, which can obtain angiographic images from different angles, increasing the observation angle and showing diseased vessels with more advantages. Three-dimensional DSA is a product of the combination of rotational angiography, DSA technology, and computerized three-dimensional image processing technology, which can display three-dimensional images of blood vessels through post-processing such as VR and surface-shaded display (SSD) by workstations. It has overcome the problem of overlapping vascular structures, to provide more anatomical details and cerebral blood flow information for the observation of vascular lesions and localization measurement as well as diagnosis of vascular stenosis, offering the necessary conditions for various interventions [18, 19]. RSM-DSA

is an alternative subtraction method for DSA. It allows the acquisition of subtraction images in a single motion after contrast injection, avoiding the tedious process of two motion acquisitions and the possibility of subtraction failure due to patient movement between acquisitions.

Cerebral angiography can be divided into whole brain angiography, selective cerebral angiography, and superselective cerebral angiography. During the operation, the femoral artery is often punctured and cannulated, bilateral vertebral arteries and common carotid arteries are imaged separately, and superselective angiography is performed according to the condition. DSA shows the full-time course of cerebral circulation and blood flow compensation, which has obvious advantages in the diagnosis and interventional treatment of intracranial vascular diseases. In cerebral vasculitis, DSA can clearly show the inflammatory changes in blood vessels caused by various reasons, such as stenosis or occlusion of blood vessels in different areas, tortuosity and stiffness of blood vessel travel, a few arterial dilatation or aneurysm caused by inflammation damaging the middle layer of the arterial wall, etc. It is the gold standard for the diagnosis of various vascular inflammatory diseases. However, the diagnosis of vascular inflammatory diseases requires a combination of clinical manifestations and laboratory findings, as some of the vascular changes in cerebrovascular inflammatory diseases are nonspecific and may even be negative. DSA can also be used for long-term follow-up observation of structural damage to the patient's blood vessels.

However, DSA has some limitation. First, its main contraindications are as follows [5]: (1) those with severe bleeding tendency; (2) those with severe cardiac, hepatic, or renal insufficiency; and (3) those with contrast allergy. Second, DSA imaging has certain limitations, mainly including the following: (1) The patient needs to be highly cooperative during the imaging and avoid all random movements; (2) although DSA is good for displaying small arterial branches, it cannot yet display tiny vessels with a diameter of <0.2 mm; (3) involuntary movements (such as swallowing, breathing, and gastrointestinal peristalsis) can produce artifacts and affect image clarity.

1.5 Radionuclide Imaging Techniques

Yongde Qin, Xiaohong Li, and Xin Gao

1.5.1 Principles of Positron Emission Computed Tomography

Positron emission computed tomography (PET) is the use of positronium nuclides to label or synthesize the corresponding imaging agent, which is introduced into the body and localized in the target organ. These nuclides emit positrons during the decay process, which, after a short distance in the tissue, interact with the negative electrons in the surrounding material, resulting in annihilation radiation and the emission of two photons with opposite directions and equal energy (511 keV). PET employs a series of detectors arranged in pairs at 180° to each other and connected to a conformal line to detect annihilating radiation photons, thereby obtaining a tomographic distribution of positronium in the body and the location, morphology, size, metabolism, and function of the lesion to diagnose the disease. Since PET utilizes positron emitter markers such as ^{11}C, ^{13}N, ^{15}O, and ^{18}F (similar to the biological behavior of H), which are essential elements in the normal tissue structure of the human body, as imaging agents and uses drugs such as deoxyglucose, amino acids, choline, thymine, ligands of receptors, and blood flow imaging agents as tracers, it can display the metabolism, function, blood flow, cell proliferation, and receptor distribution of the body and focal tissue cells at the molecular level, providing more physiological and pathological diagnostic information for clinical purposes [20].

1.5.2 Positron Emission Computed Tomography Methods Commonly Used in Infectious and Inflammatory Diseases of the Brain and Spinal Cord

1. *PET brain metabolic imaging*: The human brain is very metabolically active, and its functional activity is extremely complex. Brain metabolic imaging is of great importance in studying the changing patterns of functional metabolic activities of the central nervous system and in exploring brain diseases. Glucose is almost the only energy substance for brain tissue, and changes in the rate of glucose metabolism in the brain can reflect the functional activity of the brain. Fluorodeoxyglucose (^{18}F-FDG) is a glucose analog with the same cellular transport and hexokinase phosphorylation process as glucose but remains in brain cells after conversion to ^{18}F-FDG-6-P, which is no longer involved in further glucose metabolism. Observations and measurements of the distribution of ^{18}F-FDG in the brain will provide insight into the state of glucose metabolism in the brain. Its clinical applications mainly include localization and diagnosis of epileptic foci; diagnosis and condition assessment of Alzheimer's disease; differentiation, staging, and grading of benign and malignant brain tumors; determination of efficacy and prognosis; and diagnosis of recurrent and residual lesions. Most active foci of infection demonstrate high uptake of ^{18}F-FDG, which can therefore be utilized to detect foci of infection, respond to the glucose metabolic activity of infected lesions, and allow assessment of treatment efficacy. For PET/MRI, FDG uptake is corroborated by MRI findings.

   In addition to glucose metabolic imaging, there are also oxygen metabolic imaging (^{15}O), amino acid metabolic

imaging (^{11}C-MET, ^{18}F-FET), nucleic acid metabolic imaging (^{18}F-FLT), lack of oxygen metabolic imaging (^{18}F-FMISO), and choline metabolic imaging (^{11}C-CHO). Cerebral metabolic imaging allows to obtain cerebral oxygen metabolic rate and oxygen extraction fraction, which are important indicators of the level of cerebral oxygen metabolism. Amino acid metabolic imaging mainly reflects the level of protein anabolism in the brain, while neuronal cells in the normal adult brain are mostly mature cells; hence, there is no significant protein synthesis. The tumor cells show high amino acid uptake in conjunction with high glucose metabolism and accelerated amino acid transport to meet the demand of cell growth and proliferation, which therefore manifests as high amino acid uptake, coupled with very low amino acid uptake by normal brain cells, thus accentuating the lesion. Amino acid metabolic imaging (^{11}C-MET, ^{18}F-FET) has a low background in the brain, and infectious lesions show mild to moderate metabolic elevation. It is presently used for the differential diagnosis of infectious lesions, demyelinating lesions, and tumors. Choline metabolism is the entry of ^{11}C-CHO into the cell through specific transporters, and after intracellular metabolism, the end product phosphatidylcholine is integrated into the cell membrane. The rate of choline uptake by cells reflects the rate of cell membrane synthesis, and thus it can be used as an indicator of tumor cell proliferation and division, which is a direct or indirect tracer of tumor cell proliferation and division [21].

2. *PET neuroreceptor imaging*: Neuroreceptor imaging is designed to obtain parameters such as receptor distribution, density, and affinity of receptors by PET, which is based on receptor-ligand-specific binding through the use of positron emitting radionuclides to label specific ligands in the living human brain. The synthesis, release, binding to postsynaptic membrane receptors, and reuptake of specific central neurotransmitters can be observed using radionuclide-labeled precursors of synthetic neurotransmitters, which is called neurotransmitter imaging. The quantitative or semiquantitative parameters of central neurotransmitters or receptors can be obtained through physiological mathematical models, allowing for diagnosis, treatment decisions, efficacy assessment, and prognosis of certain neurotransmitter- or receptor-related diseases. The main neuroreceptors that are presently being studied and applied are the dopamine receptor (dopamine receptor), the acetylcholine receptor, 5-serotonin receptor, benzodiazepine receptor, opioid receptor, etc. [22].
3. *PET/MR brain imaging*:

PET/MR is a large functional metabolic and molecular imaging diagnostic device that combines positron emission tomography and magnetic resonance imaging technology. Compared with other examinations, PET/MR is highly sensitive and accurate, especially for early detection, early diagnosis, and accurate assessment of neurodegenerative diseases without obvious structural changes, such as Alzheimer's disease, epilepsy, and Parkinson's disease. In addition, it has incomparable advantages for the identification of benign and malignant intracranial malignant tumors, the determination of malignant glioma borders, the identification of posttreatment radiation necrosis and recurrence of tumors, and the accurate selection of tumor biopsy sites by other imaging means [23].

References

1. Omran AR. The epidemiologic transition: a theory of the epidemiology of population change. Milbank Mem Fund Q. 2005;83(4):731–57.
2. Wang K, Xiao J. Analysis of the principles and applications of digital X-ray technology. Med Equip. 2015;28(1):23–4.
3. Ahluwalia GK. Applications of chalcogenides: S, Se and Te. Cham: Springer; 2017.
4. Salvini E, Pedroli G, Montanari G. Digital storage phosphor radiography. Doses and image quality. Radiol Med. 1994;87(6):847–51.
5. Bai R, Zhang X. Medical imageology. 3rd ed. Beijing: People's Medical Publishing House; 2010.
6. Zhang H, Yu HL, Hu ML. Value of CT scanning methods in diagnosis of patients with intracranial infections. Chin J Nosocomiol. 2018;28(5):715–7, 725.
7. Shi M, Gao J. Clinical application of spectrum CT in angiography. Chin Med Dev. 2016;31(7):6–8.
8. Ren QG, Sli Y, Li JY. The basic principle and clinical applications of CT spectral imaging. Int J Med Radiol. 2011;34(6):559–63.
9. Huang R, Li Y. Clinical applications and research advances in energy spectrum CT. Radiol Pract. 2015;30(1):81–3.
10. Hartung MP, Grist TM, Francois CJ. Magnetic resonance angiography: current status and future directions. J Cardiovasc Magn Reson. 2011;13:19.
11. Wheaton AJ, Miyazaki M. Non-contrast enhanced MR angiography: physical principles. J Magn Reson Imaging. 2012;36:286–304.
12. Saloner D. The AAPM/RSNA physics tutorial for residents. An introduction to MR angiography. Radiographics. 1995;15(2):453–65.
13. Miyazaki M, Lee VS. Nonenhanced MR angiography. Radiology. 2008;248:20–43.
14. Moran PR. A flow velocity zeugmatographic interlace for NMR imaging in human. Magn Reson Imaging. 1982;1:197–203.
15. Moran PR, Moran RA, Karstaedt N. Verification and evaluation of internal flow and motion. True magnetic resonance imaging by the phase gradient modulation method. Radiology. 1985;154:433–41.
16. Bryant DJ, Payne JA, Firmin DN, et al. Measurement of flow with NMR imaging using a gradient pulse and phase difference technique. J Comput Assist Tomogr. 1984;8:588–93.
17. Ai M, Ruan X, Wang Y, et al. The history, current status and future trends of digital subtraction. Med Equip. 2000;13(6):1–6.
18. Gailloud P, Oishi S, Carpenter J, et al. Three-dimensional digital angiography: new tool for simultaneous three-dimensional rendering of vascular and osseous information during rotational angiography. Am J Neuroradiol. 2004;4(4):571–3.
19. Abe T, Hirohata M, Tanaka N. Clinical benefits of rotational 3D angiography in endovascular treatment of ruptured cerebral aneurysm. Am J Neuroradiol. 2002;23(4):686–8.
20. Santiago JFY. Positron emission tomography with computed tomography (PET/CT). New York: Springer; 2015.
21. Christian PE, Waterstram-Rich KM. Nuclear medicine and PET/CT. 7th ed. Amsterdam: Elsevier; 2011.
22. Wang H, Zuo C, Huang Z, et al. 11C-CFT brain PET clinical application of imaging in the diagnosis of early Parkinson's disease. Chin J Clin Med Imaging. 2010;21(4):229–32.
23. Wu Y, Sun X, Lin S, Bao Z. Application of combined PET/MR imaging. Radiol Pract. 2015;13(6):104–6.