Magnetic resonance (MR) angiography was introduced into clinical practice about 10 years ago and provides a variety of significant advantages over competitive methods in vascular imaging. Similar to color coded duplex Doppler ultrasonography (US), MR imaging techniques are able to demonstrate angiomorphology, provide information about the perivascular space, and give functional quantitative information on the basis of two-dimensional cine phase-contrast flow mapping. The main differences to computed tomography (CT) are that no ionizing radiation is involved, there is no need for nephrotoxic contrast media or even for contrast media at all, and vessels and bone can be easily distinguished in the reconstructed images. Like with CT, the vascular tree can be visualized three-dimensionally (3D) and the vascular lumen and surrounding structures can be simultaneously evaluated with MR angiography. Conventional X-ray angiography not only suffers from the inherent risk associated with the invasive nature of the technique but is also restricted to a limited number of views (projection) in a two-dimensional space. The purely luminographical display in conventional angiography presents limitations in patients in whom the vascular wall or the surrounding tissue are of major importance for diagnosis, such as in aneurysmal disease.

In this chapter the beginnings and the development of vascular MR imaging up to the current status of MR angiography will be presented.

With the detection of nuclear magnetic resonance (NMR) and its implementation into medical imaging, new insight has been gained in morphology, pathoanatomy, and function. The ability of MR imaging to visualize reliably soft tissue alterations is based on a high signal-to-noise ratio and contrast-to-noise ratio and the large variability in the contrast of structures that are invisible by other imaging modalities. The signals derive from biochemical tissue characteristics such as relaxation times and from magnetic properties. Further contributors to MR contrast are susceptibility, chemical shift, and motion.

Following the introduction of clinical MR imaging, the technique was initially used to obtain cross-sectional images in all directions and at any region of the body. Neglecting its ability to provide further information about function or pathomorphology, MR imaging was regarded as a potential substitute for CT, a technique that required ionizing radiation, and as an imaging tool which could supersede US due to the significantly improved spatial resolution and tissue characterization in a large, defined field of view.

Although the potential of NMR to acquire flow information had already been recognized during the 1950s, the technical prerequisites for acquiring sequences suitable for flow imaging were not met until the 1990s.

In a way, the imaging of vascular structures during the early phase first was an undesired side effect, comprising a variety of artifacts that were produced by vascular motion and pulsation. Through the development of today’s MR technology as well as further theoretical and practical user experience, it became possible to compensate for these artifacts or to suppress them and to visualize vascular structures.

Intravascular motion was displayed with a high contrast to adjacent tissue either without an intraluminal signal or with a high signal intensity. Nevertheless, due to the relatively long acquisition times, all kinds of physiological motion during scanning have the potential to create artifacts and distort the results.

Two solutions to these problems were provided more than 10 years ago:
1. Improving the speed of MR image acquisition, thus avoiding the problems due to physiological motion
2. Compensating for the motion-induced errors in signal registration by adjusting the measurement parameters to the motion
Both approaches are being followed; the latter offers the possibility of visualizing vascular structures directly on single slices. The additional application of reconstruction algorithms, including maximum or minimum intensity projections, can produce angiogram-like images of a certain area by suppressing the signal of stationary tissue. These images became known as “magnetic resonance angiograms.” However, the term MR angiography refers to a broad variety of MR sequences by which intra- and extravascular vessel contrast can be obtained. All MR angiographic sequences are based on the specific properties and characteristics of blood and blood flow. Minimum requirements for MR angiography are optimized contrast between vessel and background, a continuous delineation of defined vascular areas, and image information that is based on motion, i.e., blood flow movement or intravascular contrast enhancement.

Since flow phenomena can result in either a bright or a dark signal, signal displacement, and signal aliasing, a multitude of different techniques have been introduced to use these artificial signals clinically. The basic artifacts arise in almost any MR technique but play a major role in gradient echo (GRE) imaging. In these sequences, phase dependency and inflow phenomena are predominantly used for native acquisitions in MR angiography.

Bearing in mind the MR appearance of flow, flow-related MR imaging can be defined as a vascular examination method based on the biochemical and biophysical properties of blood and blood flow. It represents a method for the functional imaging of blood vessels and with which blood flow can be quantified. Due to the functional basis of the MR angiographic signals, vascular structures may not always be precisely registered because of the different flow patterns and velocities.

In this respect, MR angiography resembles color duplex US rather than conventional angiography and potentially provides both morphologic and physiologic data from the arterial and the venous circulation in the assessment of a suspected vascular disease.

On static spin echo (SE) images, blood flow appears dark, allowing depiction of both intra- and extravascular anatomy. Turbulent flow may generate a signal that cannot be differentiated from thrombus. Therefore, dynamic vascular studies using GRE techniques and phase velocity mapping techniques may help in assessing anatomical flow and flow abnormalities. MR angiography can yield information on flow direction, flow origin, and the presence or absence of col-laterals. Veins and arteries can be imaged selectively due to their usually opposite flow direction by using presaturation techniques.

However, in clinical practice several drawbacks of flow-related MR angiographic techniques were observed which limited the visualization of angiomorphology and accuracy in evaluating vascular abnormalities. Major limitations were unexpected signal voids due to phase dispersion in turbulent flow conditions, in-plane saturation, and artifacts due to respiratory and cardiac motion, vessel pulsation, and susceptibility artifacts.

The majority of these problems could be solved by the introduction of contrast-enhanced MR angiography, based on the initial work of Prince and coworkers in 1993. By coordinating the administration of a contrast material bolus with an ultrashort data acquisition period in MR angiography, motion artifacts could be widely avoided by holding the breath during imaging, and saturation artifacts were diminished significantly. Contrast-enhanced 3D data acquisition has proven to be superior to flow-related native acquisitions in angiomorphic imaging, which has ushered in a completely new era of clinical MR angiography. Acquisition of the data set during a single breath-hold became possible by shortening of the repetition time (TR) in MR angiographic sequences. As a prerequisite for this ultrafast MR angiography technique, high gradient performance was mandatory. However, because short TR strongly reduces the T1-weighted signal of the normal blood, intravenous administration of paramagnetic contrast material was required to improve the T1-weighting effect in blood. As an advantage, it could be shown that paramagnetic contrast material has far fewer side effects than X-ray contrast agents; nephrotoxicity, in particular, can be excluded.

In order to optimize arterial contrast, administration of the contrast bolus must be timed so as to guarantee that the maximum contrast appears primarily when the central lines of the k-space are filled, whereas peripheral k-space filling is responsible for spatial resolution and imaging of small vascular structures with low contrast. The 3D data set has to be acquired during the first pass of contrast material, covering the arterial phase, whereas in repetitive acquisitions of one or two additional 3D data sets, the venous phase can be visualized, optimizing the delay between arterial and venous acquisition. Fat saturation and subtraction techniques as well as high-resolution acquisition can optimize image quality. With dynamic table translation technique, the entire aorto-iliac and lower extremity