Image Processing and Visualization

An Offprint from

Peter A. Rinck

Magnetic Resonance in Medicine

A Critical Introduction

The Basic Textbook
of the European Magnetic Resonance Forum

13th edition • 2021
335 figures, 36 tables

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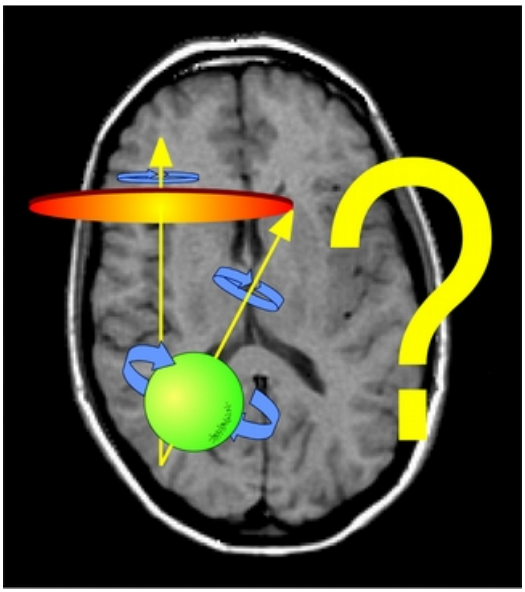
Foreword



"Why, sometimes I've believed as many as six impossible things before breakfast."
The White Queen in Lewis Caroll's
'Alice Through the Looking Glass'.

We like books – printed on paper, if possible with a beautiful hard-cover binding. Thus, putting this standard textbook on the internet some years ago was a challenge. Now we return with a printed version of the magnetic resonance textbook. The reasons I have described elsewhere.[1]

Celebrating the 50th anniversary of MR imaging in 2021 was a good occasion to publish a new edition. The textbook-child has grown up, become an adult or, in our case – a rather successful standard textbook. The reviews and public reaction to the book were extremely positive.

The first version of this primer – a little booklet – was written at Paul C. Lauterbur's laboratories in the early 1980s. Lauterbur was the father of MR imaging and received the Nobel Prize twenty years later. The text was intended to be used as the Basic Textbook for EMRF, the European Magnetic Resonance Forum. After Lauterbur saw the first edition, he commented: "It looks like a fine book, especially for residents, nurses, and technicians."

Initially we thought this statement was not very encouraging, but in hindsight this was exactly what we had intended to write. We worked on it for another twenty years – and finally Lauterbur found the last edition he read before his death "gratifying". How-

1 Rinck PA. An expensive dilemma: Tablets versus textbooks. Rinckside 2015; 26,7: 17-19.

ever, the target audience today includes scientists and university professors. They should be able to acquire a basic knowledge which enables them to pursue studies of their own and to cope with some of the most common problems, among them tissue relaxation, image contrast and artifacts or questions concerning possible hazards to patients – and to become aware of how to perform reliable research, and to ask and be critical.

The main author and the contributors have not attempted to cover the field completely nor to be exhaustive in the topics discussed, as the field of magnetic resonance still is in a permanent stage of development and therefore changing year by year. Clinical MR machines and even equipment sold for scientific purposes have been increasingly altered into push-button black boxes with pre-fab, given and unchangeable protocols. We are not interested in certain gadgets or "apps" of commercial machines, and won't mention or describe them. We try to explain the fundamentals any user should know and understand.

As with everything in life, MR imaging does not only require knowledge of facts but also of background information and of the historical development of the field for critical decision making. Therefore we have interspersed some subjective, critical, and opinion-oriented sections – interludes – intended to offset the technical nature of the teaching sections and provide some insights into more practical questions faced by MR users.

Most of them were taken from *Rinckside* (www.rinckside.org), a collection of columns published since 1990.

Many of the recent developments concerning MR equipment and its medical and biological applications have turned away from magnetic resonance itself to novel engineering and software approaches in image processing including artificial intelligence. Techniques, ideas and algorithms were imported from fields outside medicine and adopted by software engineers with little or no background in MR and medicine nor insight into medical needs. We mention some of the prime approaches without going into details of signal or image processing – they are of no importance for the understanding of fundamental facts of magnetic resonance imaging.

There has been a long list of contributors to this and earlier versions (see page 418). Their support, ideas, dedication, and feedback have added much to the quality of this work. This book was peer-reviewed by a number of competent reviewers in different fields whom I thank for their efforts.

If you want to learn something about magnetic resonance imaging or its applications choose your topic of interest. If you want to learn it from scratch start with Chapter 1; and if you want to air your brain, read the interludes that are scattered in between.

If you find any mistakes in this book, rest assured that they were left intentionally so as not to provoke the gods with something which is perfect. Still, we would be happy about your feedback. We hope that this textbook will be useful for you and that you will enjoy it. If you have comments or suggestions, please write to us.

Peter A. Rinck, June 2021

Contents

Chapter Fifteen

Image Processing and Visualization

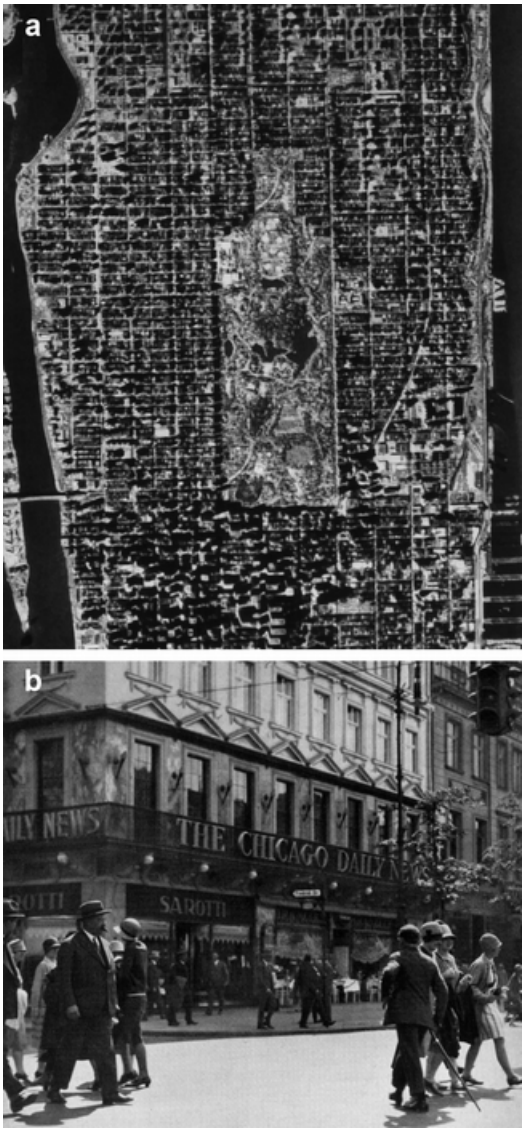


Figure 15-01:
Where and when were these pictures taken – and what do they show? Think twice … answers overleaf.

Introduction

Basically all digital images are processed in one kind or another. When reading MR images, one always should be prepared for the unexpected. Digitized imaging brings more of the unexpected into our lives. Still, there are some easily recognizable features in most images (Figure 15-01).

Image processing was already on its way to becoming an established field of research in its own right when clinical MR imaging equipment became available in the early 1980s. The digital nature of MR imaging, coupled with a wide range of applications, spurred an enormous activity in image-processing of MR imaging data in the last fifty years.

Computer assisted detection or diagnosis (CAD) systems were developed to find and highlight suspicious regions or structures in images of the human body by pattern recognition. They are employed in, e.g., the search for breast, bone, lung or metastatic cancer. These artificially intelligent (AI) systems show amazing performance. However, they can also cause misclassification of images caused by hardly perceptible perturbations in the image data and thus become detrimental. The reason for such failures are unknown.[290]

290 Szegedy C, Zaremba W, Sutskever I, Bruna J, Erhan D, Goodfellow I, Fergus R. Intriguing properties of neural networks. arXiv:1312.6199. 2014; 1-10.

Answers to the questions of Figure 15-01

These questions were just asked to confuse you. You might have thought the answers were easy. Of course, they were.

(a) Where: A bird's-eye view of Central Park in Manhattan. Wrong: This is a vodka commercial with a vodka bottle which looks like Central Park. This picture has been image-processed – and the East River is in the west.
Even if you believe that you know what you are seeing – think twice.

(b) When: Correct – before World War II (in 1928). Where: You are wrong – not in Chicago (even if there is a commercial for the Chicago Daily News), but in Berlin (at the corner of Unter den Linden boulevard and Friedrich Strasse in the city center).

Learning point: Always check the patient's history before you read your images and make a diagnosis – even when using AI support.

In this chapter we give a brief description of image-processing techniques that have been applied to MR imaging. We also describe the somewhat related field of visualization techniques, with a special focus on 3D visualization methods. Some of the methods mentioned here relate directly to the next chapter on dynamic imaging.

Involuntarily, image processing can add to the existing delusion and bias in image reading and lead to preconceived but wrong diagnoses (Figure 15-01 and Figure 16-01). Unrecognized optical and mental illusions caused by artifacts created by image-processing algorithms may amplify such errors (Figure 15- 02). These problems are beyond the scope of this introduction to MR imaging; they are treated in detail elsewhere.[291]

291 Frisby JP. Seeing: Illusion, brain and mind. Oxford: Oxford University Press. 1979.

Gray Scale and Color Images. The introduction of color images is a recurrent and lasting topic in diagnostic imaging. The contribution of colors to imaging diagnostics, in particular high-resolution images, is much debated; colors do not add any provable diagnostic facts. All digital images are *per se* gray scale images. They can be 'artifically' colored (*pseudo colors*). MR images are always gray-scale images; colored

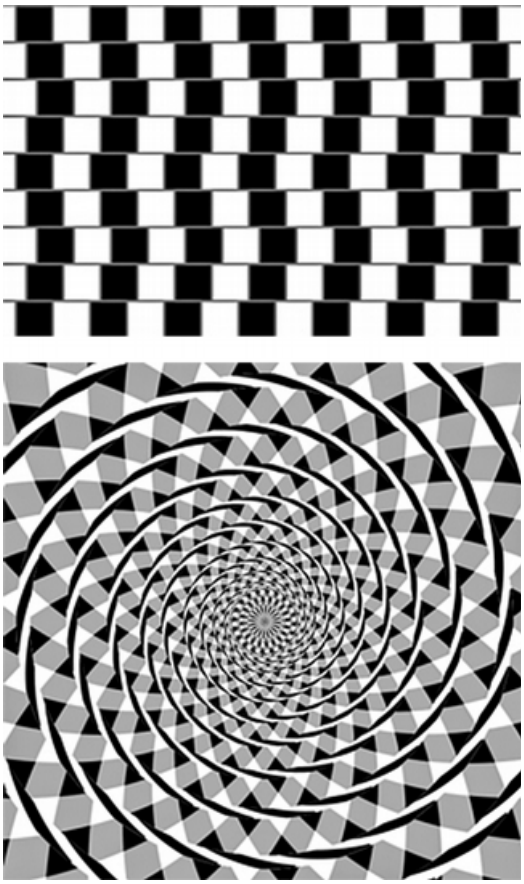


Figure 15-02:
Top: The coffee house wall illusion – in reality all lines are parallel.
Bottom: Fraser's spiral – in reality there are only circles.

MR images are only used as show effects. In diagnostic MR imaging, colors lack the dynamic range of gray scale images and image windowing is not possible.

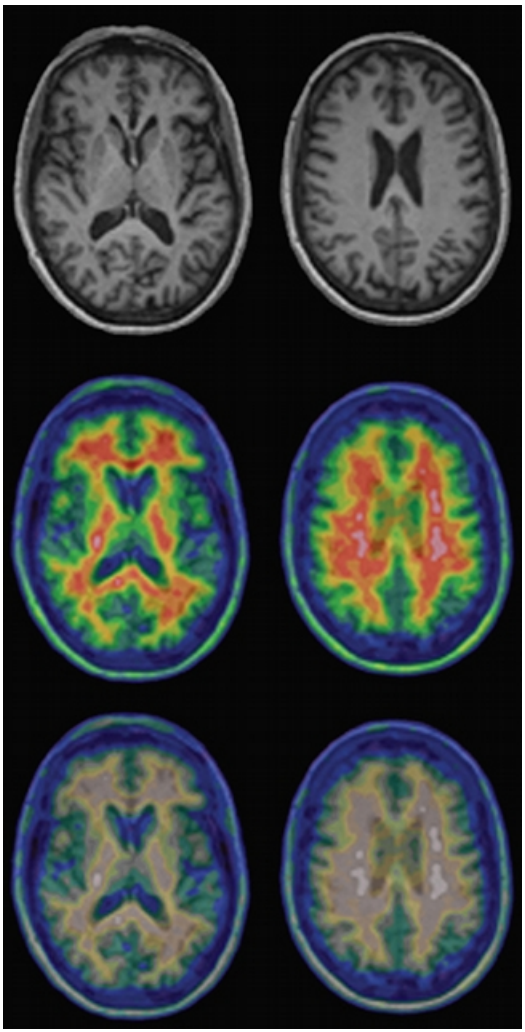


Figure 15-03:
Top: Regular T1-weighted gray-scale MR images of a healthy volunteer. **Center and bottom:** PET-MRI fusion images of the same person. The upper row of the pseudo-color images shows the normal images; the lower row shows the same images as seen by a person with red-green deficiency (deuteranomaly).

However, pictures of a number of MRI offsprings (e.g., MR angiography, dynamic contrast-enhanced MRI, functional MRI, MRI tractography, PET-MRI fusion images) often contain overlayed colored areas representing usually the lower resolution imaging technique.

Colors are subjective qualities. They might confuse, bias, and lead to a loss of information. In general, their perception is not well understood.

One example is the semiotics of color-coding in BOLD imaging: Colors are assigned to degrees of statistical significance, then turned into colored pixels, combined into blots, and overlayed on high-resolution MR brain images to reveal 'brain activation', i.e., regions of relatively more or less blood in an excited state compared to a rest state.

However, the color scale used elicits a biased reaction in many observers – obfuscating a neutral interpretation of the results (for details cf. Chapter 11, page 217).

Another problem is the human eye. In the central part of the retina, there are approximately six million cone cells which are responsible for color vision.

However, 8% of the male population and 0.5% of the female population in Europe and North America suffer from a color vision deficiency.

The most common one is deuteranomaly where people (radiologists) perceive green, red and purple as a grayish shade and are unable to identify red or green colored areas of these images (a simulation is shown in Figure 15-03).

Some Fundamentals

The main objective of medical image processing is to facilitate the gathering or provision of information not easily seen, or not seen at all, on unprocessed images.

In general, the processing of digitally acquired images is aimed at improving pictorial information for human interpretation and (or) processing data for autonomous machine perception. Both aims have been targeted in magnetic resonance imaging and in both areas successful applications have been found.

All computed image-processing requires digitized imaging. In digitized radiology, the equivalent of a regular x-ray is taken and digitized directly by a specialized x-ray system. In nuclear medicine, CT, and MR, imaging slices through the human body are acquired and subdivided into volume elements. Then, the numerical signal from each voxel, in turn, can be translated into a distinct shade of the gray scale and be represented as a picture element in the final image (Figure 15-04). Both, single images or a series of similar images can be manipulated, e.g., by noise reduction, edge or contrast enhancement.[292]

In *multichannel imaging*, several channels representing *n* different parameters can be acquired simultaneously or by consecutive procedures, leading eventually to *n* images of exactly the same object (Figure 15-05).

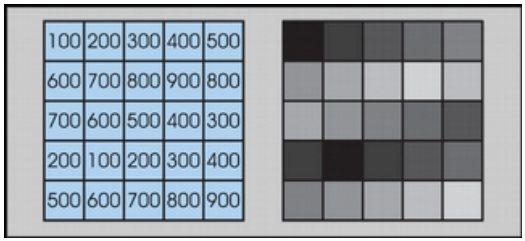


Figure 15-04:
Numerical image date output (left) turned into gray-scale image (right). Typically, one finds medical images with an image matrix of 256×256, 512×512, or 1024×1024 and 256 gray levels.

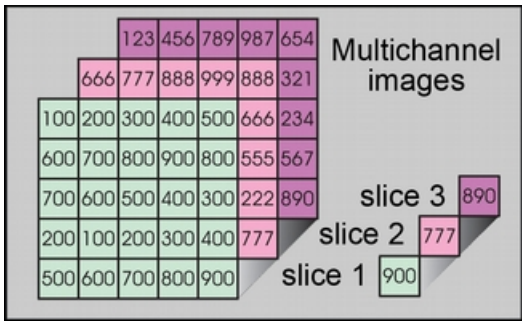


Figure 15-05:
If multichannel images of the same object are properly aligned, it is easy to compare or compute their signal intensities.

Image-processing allows the connection of picture element data of the same location in different images with changed parameters; known connections can be computed, e.g., by using appropriate equations.

Such procedures may extract additional information or allow quantification of data and thus a – perhaps – "objective" definition of structures, tissues, or metabolic processes.

Several single images can, e.g., be added to a new multispectral image (synthetic image) which does not necessarily add useful information or even depict reality (Figure 15-06).

292 Godtliebsen F. A study of image improvement techniques applied to NMR images. Doctoral thesis. Trondheim: The Norwegian Institute of Technology, Division of Mathematical Sciences 1989.

Details on image processing can be found in a number of monographs.[293, 294]

There are different ways of classifying image-processing techniques, for instance, they can be defined by what they are supposed to achieve.

Types of techniques include *noise reduction, image segmentation, feature extraction,* and *classification.*

Whereas *noise reduction* is of vital importance for more noisy modalities like ultrasound, MR imaging has, due to a rapid development of MR hardware and software, not the same need for such techniques, perhaps with the exception of dynamic imaging (see Chapter 16).

However, *image segmentation* and *image classification* have found much more widespread use in MR imaging, partly due to the possibility of acquiring multichannel data suitable for such processing.

Another important group of image-processing techniques is *image registration* or *image alignment*, which sometimes employs image segmentation techniques to align images. Image registration is important for aligning multimodality data (for instance, nuclear medicine data and MR imaging data from the same patient) or registration of time series. A specific type of time series (dynamic contrast-enhanced MR imaging) is described in Chapter 16. Furthermore, time series can also be used for monitoring tumor growth or growth of bones in children.

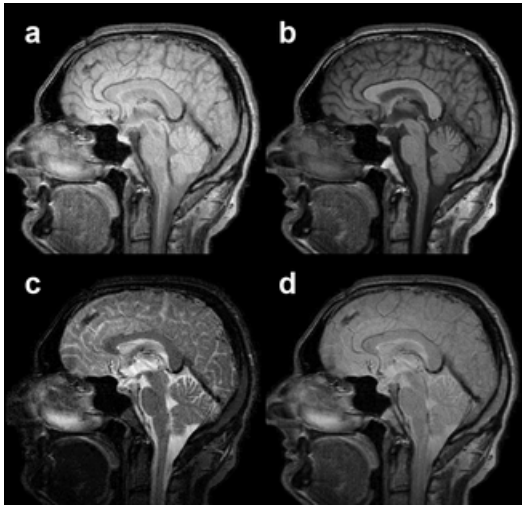


Figure 15-06:
Examples of multichannel images: **(a)** proton-density-weighted, **(b)** T1-weighted, and **(c)** T2-weighted images of a slice through the brain.
The anatomic location of the pixels is exactly the same; according to image weighting the pixel representation is different.
(d) is a pixel-by-pixel compilation of images a-c. This synthetic image does not reveal any additional diagnostic information.

Another important type of MR imaging time series is BOLD functional MR imaging (fMRI) of the brain. Image registration is routinely performed on fMRI data.

Improvement of diagnostic performance to reduce the ever existing level of uncertainty is one of the main propelling forces in diagnostic imaging research.

Since the human visual-perception system is unable to perform multichannel analysis in order to achieve a new dimension, image processing developed in parallel to the introduction of MR imaging as a clinical tool.

293 Gonzalez RC, Wintz P. Digital image-processing. 3rd ed. Upper Saddle River, NJ (U.S.A.): Pearson Prentice Hall 2008.

294 Russ JC, Brent NF. The image-processing handbook. 7th ed. Boca Raton (U.S.A.): CRC Press 2017.

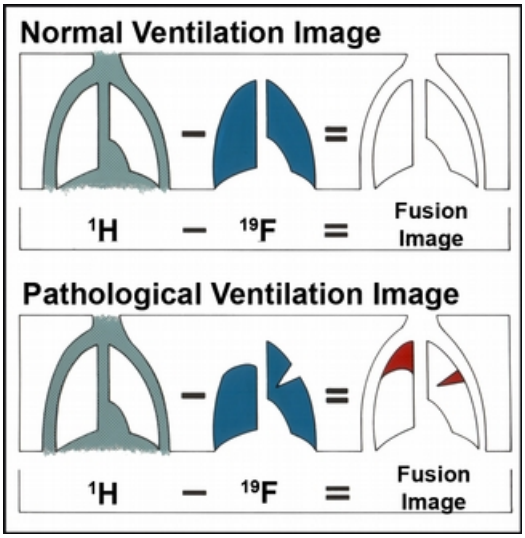


Figure 15-07:
Diagram explaining the theory of the first fusion images in MRI (1982). Subtraction of hydrogen and fluorine images of the lungs.

Researchers wanted to detect any message, possibly hidden, in a single MR image or a series of MR images. Given that only minimal information existed about how to approach this scientific problem, the course of research was mostly empiric.

Historically, the following main lines of approach were followed:

- subtraction or superposition (overlay, data fusion) of multichannel images;
- quantification of MR parameters, i.e., T1, T2 and proton density;
- image segmentation and multispectral analysis;
- 3D visualization.

Subtraction or Superposition Images

Multispectral images of the same body region can simply be overlaid to give an impression of the exact location of certain contrast-enhanced structures (data fusion). Usually, a high spatial resolution T1-weighted MR image is used as a background image to show the anatomical structures and the contrast-enhanced image is projected onto this picture.

In MR imaging this has been first shown with perfluorinated ventilation images in 1982 (Figure 15-07 [295]).

Today the method is used as a multiparametric or multimodal fusion of data as well as longitudinal (time domain) integration of single modality data, commonly applied in fMRI studies or in intermodality comparison between, e.g., CT or MR and PET images. Here, the information obtained from PET is overlaid or imprinted onto the more detailed anatomic images acquired with MR imaging or CT.

Practical Applications. The method is useful since it allows a better visualization to locate certain processes. The implementation is relatively simple.

295 Rinck PA, Petersen SB, Heidelberger E, Lauterbur PC. NMR ventilation imaging of the lungs using perfluorinated gases. Proceedings. The Society of Magnetic Resonance in Medicine. Second Annual Meeting. San Francisco 1983, 302-303, and: Magn Reson Med 1984; 1: 237.

– Rinck PA, Petersen SB, Lauterbur PC. NMR-Imaging von fluorhaltigen Substanzen. 19-Fluor Ventilations- und Perfusionsdarstellungen. RöFo - Fortschr Röntgenstr 1984; 140: 239-243.

It is mainly applied as an auxiliary tool to facilitate visualization of enhancement visible on postcontrast images (Figure 15-08), but also in MR angiography to highlight veins after subtraction of the CE-MRA images of the arterial phase, and in MRSI (Figure 05-08).

Quantification of MR Parameters

With numerous tissue parameters, MR imaging has substantial – theoretical – potential for tissue discrimination in different organs. The most important intrinsic contrast factors are proton density, T1 and T2 relaxation, and bulk flow.

The use of relaxation times for medical applications was first proposed in 1955.[296]

Voxel-by-voxel *in vivo* relaxation-time measurements, partly turned into T1- and T2-maps, have been tried out over the years by a large number of researchers.[297] However, parametric T1 and T2 images did not enter into clinical routine. They were restricted to a single parameter only and revealed less information than images representing several parameters combined with different parameter-weighting.

This was one of the first major lessons to be learnt in MR image-processing: if one has more than one known factor influencing the contrast of an image, and if the change in contrast is perceivable by the human eye, it is not worthwhile to extract such a factor to create a parametric image. This holds in particular if this factor cannot be quantified exactly. In the case of relax-

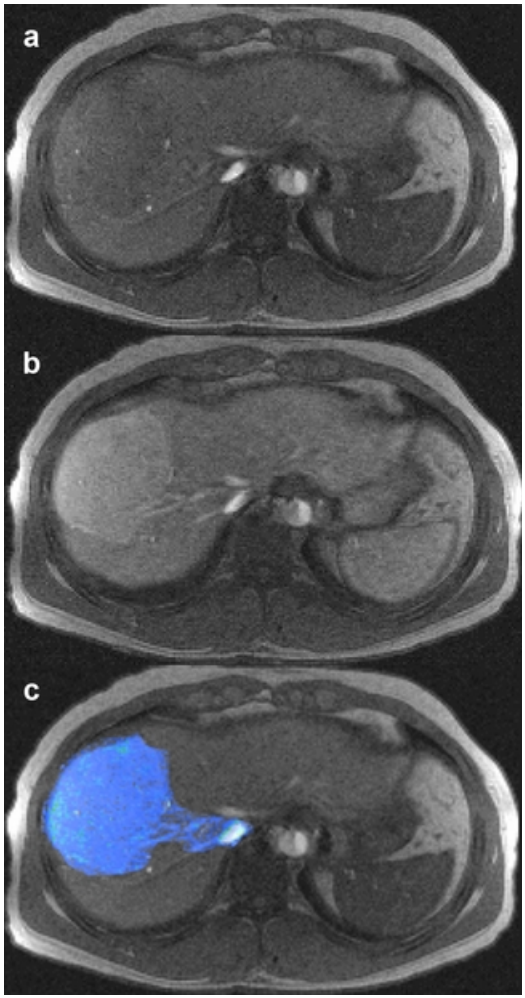


Figure 15-08:
Multichannel images: **(a)** plain image of a liver, **(b)** contrast-enhanced liver, with depiction of focal nodular hyperplasia, part of a dynamic series, and **(c)** overlay of enhanced lesion on plain liver image.

296 Odeblad E, Lindström G. Some preliminary observations on the proton magnetic resonance in biological samples. Acta Radiol 1955; 43: 469-476.

297 Skalej M, Higer HP, Meves M, Brückner A, Bielke G, Meindl S, Rinck PA, Pfannenstiel P. T2-Analyse normaler und pathologischer Strukturen des Kopfes. Digit Bilddiag 1985; 5: 112-119.

ation times, only an estimation is possible *in vivo*.

In 1985, it was finally realized that even carefully performed *in vivo* T1 or T2 measurements cannot be used as a diagnostic method in cancer detection, characterization, or typing.[298] Quantification does not allow reliable tissue identification and classification.

Synthetic or simulated images. For specific applications, pure relaxation time maps can be used to create synthetic MR images and to simulate image contrast behavior. Such techniques were proposed very early in MR imaging in the first half of the 1980s to allow fast retrospective optimization of image contrast.

A number of publications dealt with this[299, 300, 301, 302] and dedicated software programs, e.g., MR Image Expert[303] were developed for educational and research purposes. Several examples of *simulated* or *synthetic* MR images are shown in Chapter 10.

CAD as CAD can ...
Computer assisted diagnostics and AI: Are there hidden messages in multichannel images or in any other digitized and processed synthetic data? A comment – on page 301.

The procedure leading to synthetic images requires several steps. High-quality, low-noise simulations are based on true T1, T2, and proton density maps of the same slice or volume. Then pixel-by-pixel signal intensities can be calculated with standard equations: the operator-selected variables are, for instance, TR, TE, TI, and FA.

Such simulated images have substantially less noise than images acquired directly on an MR machine. Applying computer simulation for sequence optimization is time and cost efficient compared to *in vivo* experiments. They can be used when looking for specific anatomical or pathological features or to evaluate best pulse-sequence parameters for contrast agent enhancement or comparison of contrast at different field strength.

MR Image Expert, the simulator used for this textbook (Figure 15-09), could also

298 Rinck PA, Meindl S, Higer HP, Bieler EU, Pfannenstiel P. MRI of brain tumors: discrimination and attempt of typing by CPMG sequences and in vivo T2-measurements. Radiology 1985; 157: 103-106.

299 Bielke G, Meves M, Meindl S, Brückner A, Rinck P, von Seelen W, Pfannenstiel P: A systematic approach to optimization of pulse sequences in NMR-imaging by computer simulations. In: Esser PD, Johnston RE (eds.): The Technology of NMR. New York. The Society of Nuclear Medicine Computer and Instrumentation Councils. 1984. 109-117.

300 Bobman SA, Riederer SJ, Lee JN, Suddarth SA, Wang HZ, Drayer BP, MacFall JR. Cerebral magnetic resonance image synthesis. AJNR Am J Neuroradiol 1985; 6: 265-269.

301 Riederer SJ, Suddarth SA, Bobman SA, Lee JN, Wang HZ, MacFall JR. Automated MR image synthesis: feasibility studies. Radiology. 1984; 153: 203-206.

302 Torheim G, Rinck PA, Jones RA, Kværness J. A simulator for teaching MR image contrast behavior. Magn Res Materials 1994; 2: 515-522.

303 Torheim G, Rinck PA. MR Image Expert - interactively teaching contrast behavior in magnetic resonance imaging. In: Lemke HU, Vannier MW, Inamura K, Farman AG (eds.): Computer Assisted Radiology, CAR '96. Amsterdam: Excerpta Medica 1996, 619.

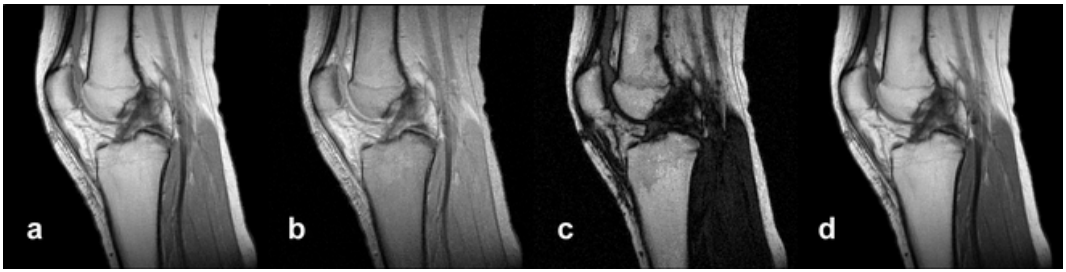


Figure 15-09:
Simulation of an MR examination of a normal knee at 1.5 T. Series of synthetic inversion-recovery images; parameters TR|TE|TI: **(a)** 1000|10|20; **(b)** 1000|10|100; **(c)** 1000|10|260; **(d)** 1000|10|500.
Simulation software: MR Image Expert®

be employed, e.g., for clinical imaging if integrated into a suitable MR equipment. The drawbacks of such image-processing programs are their dependence on specific "clean" data acquisition sequences such as spin-echo or inversion-recovery pulse sequences with known contributing components where signal intensities can be exactly and reproducibly calculated.

In addition to the factors mentioned above (exclusion of many parameters influencing image contents and contrast, e.g., multiexponential decays, diffusion, and flow), *multispectral processing* and *feature extraction* for the creation of synthetic images are cumbersome and prone to substantial mistakes.

More so, in the brain, for instance, absolute signal amplitudes are proportional to the water content, not to "proton density" because myelin lipids do not contribute to the signal,[304] another of the many features that cannot be simulated. The sometimes proposed *fingerprinting* based on multiparametric data collection is unreliable and impracticable in diagnostic routine.

Synthetic images cannot be used to quantify data (e.g., relaxation constants or proton density in tissues).

T1 maps are used in research as the basis for estimating tissue concentrations of contrast agents in dynamic imaging.

Here, two measurements are necessary, one before injection of the contrast agent, a second one after injection together with drawing a blood sample to determine the blood concentration of the contrast agent. It is rarely used in clinical routine.

Image Segmentation and Multispectral Analysis

Space and military technologies were the forerunners of many image-processing applications which later found their way into medical imaging.

One of the most important was the Landsat program of NASA. It created sets of images of the earth consisting of four or

304 Fischer HW, Rinck PA, Van Haverbeke Y, Muller RN. Nuclear relaxation of human brain gray and white matter: analysis of field dependence and implications for MRI. Magn Reson Med 1990; 16: 317-334.

more images of different spectral windows (usually, two within the visible spectrum and two within the infrared spectrum).

Similar approaches are used today in medical image processing. Image segmentation is one of the most important tools in automated image analysis.

Plain and postcontrast T1-weighted, T2-weighted, and diffusion images can be used as *multispectral images*. Reducing the representation of an image to a small number of components was one of the image-processing projects based on such pictures, a process called *feature extraction*.

It permits the separation of the basic parts of an image by sets of features that can be extracted from the image (or several images) and, in turn, then can be used to calculate other features such as edges and textures.

Segmentation is also applied in preprocessing of images for multimodality image registration. Image segmentation can be used in static images and, quite important for the use of contrast agents, in dynamic time-varying images.

The detection of gray-level discontinuity allows the highlighting of points, lines, and edges in an image.[305, 306]

Similarity techniques reveal areas of similar signal intensities using thresholding,

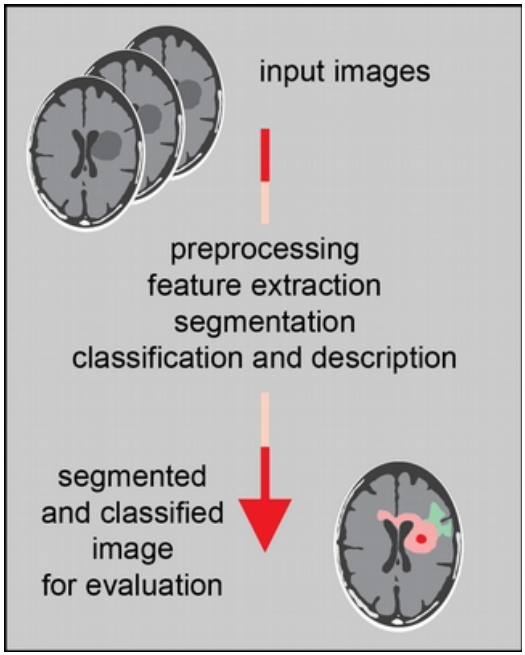


Figure 15-10:
Steps in image analysis: preprocessing improves the quality of the image by reducing artifacts; feature extraction and selection provide the measurement vectors on which segmentation is based. After segmentation, classification and description allow pattern recognition.

region growing, as well as region splitting and merging.

An overview of the components of an image-analysis system is given in Figure 15-10. A detailed description of segmentation is beyond the limits of this chapter, but is available in other treatises.[307, 308, 309] Multispectral models can be divided into super-

305 Bezdek JC, Hall LO, Clarke LP. Review of MR segmentation techniques using pattern recognition. Med Phys 1993; 20: 1033-1048. [review].

306 Lundervold A, Myhr G, Bosnes V, Myrheim J. Automatic recognition of pathological tissues in the central nervous system using MRI contrast agents and pattern recognition techniques. Oslo: Norwegian Computing Center, Report 858, 1992.

307 Gonzalez RC, Wintz P. Digital image-processing. 3rd ed. Upper Saddle River, NJ (U.S.A.): Pearson Prentice Hall 2008.

308 Clarke LP, Velthuizen RP, Phuphanich S, Schellenberg JD, Arrington JA, Silbiger M. MRI: Stability of three supervised segmentation techniques. Magn Res Imag 1993; 11: 95-106.

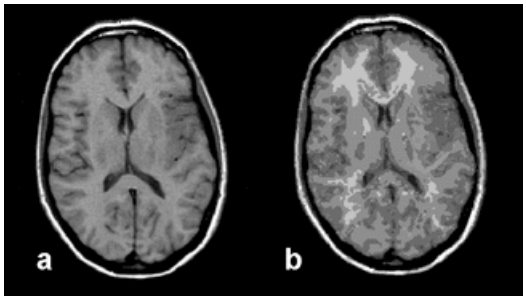


Figure 15-11:
Image segmentation: **(a)** original brain image, and **(b)** segmented image presenting 90 different tissue components.

vised and unsupervised models. An unsupervised classification (like cluster analysis) into connected regions is generally sufficient to provide good partition of an image into relevant component structures. Supervised pattern recognition is mainly successful where a reliable classification can be expected on the basis of a priori knowledge of the tissue parameters.[310]

The classical example is gray- and white-matter separation on the basis of relaxation time data (Figure 15-11).

Practical Applications. In medicine, segmentation is applied for the division of images into components reflecting the same or similar tissues.

Today, the concept of segmentation and its application of volumetry have become fast and clinically usable. Segmentation allows identification of anatomical areas of interest for diagnosis and therapy, for instance for planning of surgery.

Measurement of tumor volume before and after treatment has become a relatively easy task with image segmentation. Among other applications are quantitative measurements of brain atrophy in patients with Alzheimer's disease or alcoholic brain damage.

In cardiac MR imaging segmentation methods and contour-detection methods have been successfully applied to detect the borders of myocardium in order to calculate parameters like ejection fraction and myocardial mass. Automatic contour detection can be used for the three-dimensional depiction of bone or soft tissue structures, e.g., to produce prostheses.

Three-Dimensional Visualization

As with most imaging modalities, MR imaging data are normally presented as two-dimensional gray-scale images. However, MR imaging is essentially a 3D method and can produce three-dimensional data sets of virtually any body organ.[311]

The simplest way of visualizing such data sets is by letting radiologist flip through the set displayed as slices of 2D images, leaving it up to them to visualize the structures.

309 Russ JC, Brent NF. The image-processing handbook. 7th ed. Boca Raton (U.S.A.): CRC Press 2017.

310 Alaux A, Rinck PA. Multispectral analysis of magnetic resonance imaging: a comparison between supervised and unsupervised classification techniques. in: Higer HP, Bielke G (eds). Tissue characterization in MR imaging. Berlin: Springer 1990. 165-169.

311 Aichner FT, Felber SR, Muller RN, Rinck PA (eds.): Three-dimensional magnetic resonance imaging. An integrated clinical update on 3D-imaging and 3D-postprocessing. Oxford: Blackwell Scientific Publications 1994.

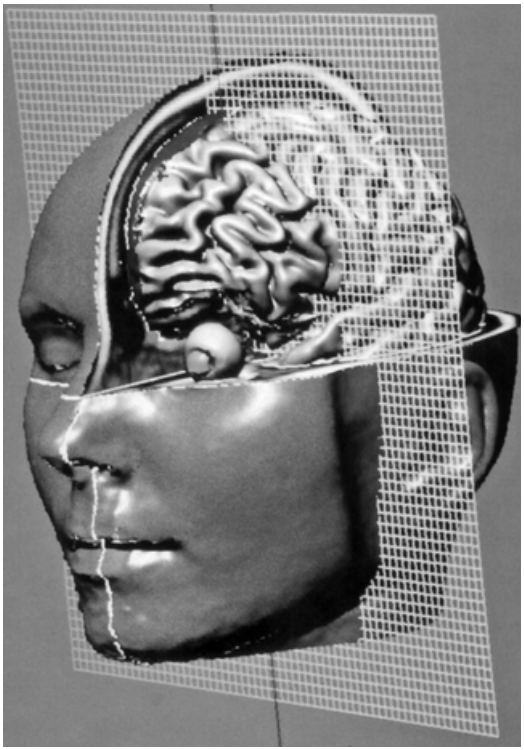


Figure 15-12:
Dissection of an MR imaging-based head model. A wire mesh is used to define cut planes. Similar reconstructions can be used in surgery and radiation therapy planning. One of the main problems in 3D image-processing is that objects within the 3D domain may obscure each other. Therefore any visualization must be preceded by a segmentation step in which 3D regions belonging to an organ must be identified.

Whereas this approach is suitable for some purposes, like diagnosis, it is less suitable for other purposes, like surgical planning or radiotherapy planning.

Thus, there is a need for 3D visualization techniques.

By performing segmentation, surface- or volume-rendering techniques can be applied.[312] The advantage of surface-rendering techniques is that they are easy and fast to visualize and manipulate (by rotation, zooming, etc.).

Since a segmentation has been done, it is possible to manipulate the 3D data set by removing tissues, request volumes and sizes.

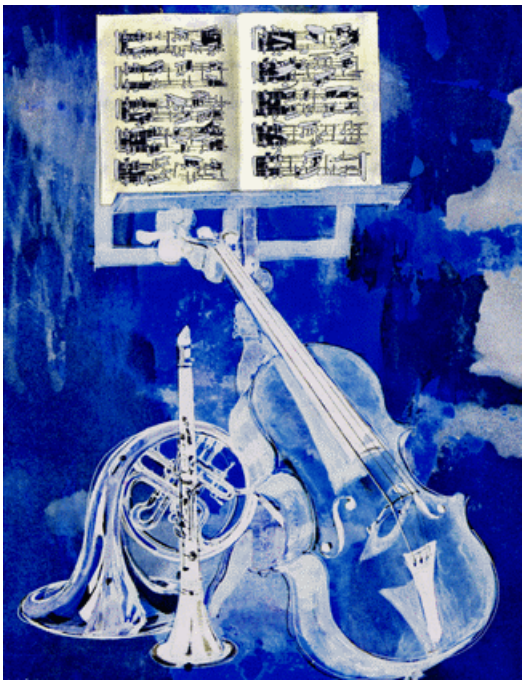
The disadvantage is that segmentation of the data is required before visualization can be performed, and that some information is lost in the segmentation step. An alternative technique is volume-rendering. Volume-rendering does not require segmentation.

However, the method requires more powerful computers to be fully interactive, and normally some interaction to visualize structures of interest (Figure 15-12).[313]

312 Maintz JB, Viergever MA: A survey of medical image registration. Med Image Anal 1998; 2: 1-36.

313 Tiede U, Bomans M, Höhne KH, Pommert A, Riemer M, Schiemann T, Schubert R. A computerized three-dimensional atlas of the human skull and brain. In: Aichner FT, Felber SR, Muller RN, Rinck PA (eds.): Three-dimensional magnetic resonance imaging. An integrated clinical update on 3D-imaging and 3D-postprocessing. Oxford: Blackwell Scientific Publications 1994. 61-74.

CAD as CAD can



Two years ago my banker told me, beaming with joy, that his bank had helped a medical company go public and that he had bought some shares for me. "I have seen what they are doing, it's just really fantastic: computer-aided detection and computer-aided diagnosis – CAD. Artificial intelligence, you know."

He was hardly stoppable on the phone when he explained to me what CAD can do and what the newcomer to the stock exchange will do: assisting any kind of doctor or paramedic in the interpretation of digital images, including CT, MRI, and PET. Like a pro, he talked about image processing, artificial intelligence, mammography, medical screening, and lung cancer. And they had something, some completely new technology, that nobody else had.

They must have invented something I didn't know about, I thought. I hadn't followed closely the development of CAD for 15 years. After several years doing research in automated information extraction from MR images, others and I had come to the conclusion that such methods are mostly unreliable in clinical routine. A breakthrough would be good for the new company – and hopefully good for me too.

• Some nights ago, I stumbled across an interesting and entertaining software program on the Internet. It was also a kind of computer-assisted diagnosis, created by Dmitry Chestnykh, a 28-year-old Russian software programmer.[314] The algorithms of the program analyze the writing styles of

314 Chestnykh D. I write like. http://iwl.me.

people and ascribe them to an author. Works from 50 of the main authors of the English language have been fed into the system and can be compared to text samples. I tried it.

First, I typed in part of a column I had written last year. I received a diagnosis: "You write like H.P. Lovecraft." I had never heard of Lovecraft, but found out that he was an American author of fantastic and macabre shorts stories. It's an interesting description, and it challenged me.

Copy and paste is easy. So I pasted more columns into the "How do I write?" form. The responses changed from Lovecraft to Arthur C. Clarke, back and forth. Clarke was another science fiction writer.

Then I copied and pasted two pages of Ernest Hemingway's prose from his story "A clean and well-lighted place." It was written like Ernest Hemingway. I tried Hemingway again; he was now writing like James Joyce. Joseph Conrad writes like Agatha Christie, Agatha Christie writes like Isaac Asimov or perhaps H.P. Lovecraft.

I got more curious and pasted one of my columns translated into Russian in Cyrillic into the form. In Russian, I write in the style of Douglas Adams, who was British. Personally, I don't believe that I write science fiction or horror columns.

The computer-assisted diagnostic program for literature works at random.

• CAD in mammography, however, does not work at random. In a study published some weeks ago, Joshua J. Fenton and his colleagues of the University of California at Davis analyzed data from more than 1.6 million screening mammograms carried out between 1998 and 2006. They found:

> "CAD use during film-screen screening mammography in the United States is associated with decreased specificity but not with improvement in the detection rate or prognostic characteristics of invasive breast cancer."[315]

An accompanying editorial published in the same issue of the Journal of the National Cancer Institute is worthwhile reading – for me it is the paper of the month. It's "CAD as CAD can." The author, Dr. Donald A. Berry from the M.D. Anderson Cancer Center in Houston, sums up as follows:

> "An argument for the use of CAD with film or digital mammograms is that it will get better over time. Fine. Researchers and device companies should work to make the software ever better. But this should happen in an experimental setting and not while exposing millions of women to a technology that may be more harmful than it is beneficial."[316]

• When I recently checked my share portfolio, the value of the CAD company had dropped from 50 euros (around $70 U.S.) to 3 euros (around $4 U.S.). "Their programs seem not exactly to work as thought," my banker told me. "It's a write-off." Indeed.

Abridged from: Rinck PA. CAD as CAD can. Rinckside 2011; 22,9: 17-18.

315 Fenton JJ, Abraham L, Taplin SH, et al. Effectiveness of computer-aided detection in community mammography practice. J Natl Cancer Inst. 2011; 103(15): 1152-1161.

316 Berry DA. Computer-assisted detection and screening mammography: Where's the beef? J Natl Cancer Inst. 2011; 103(15): 1139-1141.

The Author

Peter A. Rinck is a University Professor of Radiology and Magnetic Resonance (*emeritus*) and has a Doctorate in History of Medicine.

After a classical school education he attended medical school in Berlin (Free University of Berlin) and served his internship and residency in radiology, nuclear medicine and radiation therapy at Charlottenburg University Hospital in Berlin.

Afterwards, until 1983, he was involved in the very early development of magnetic resonance imaging as Senior Research Associate at the State University of New York at Stony Brook where he worked in Paul C. Lauterbur's research group (Nobel Prize in Medicine 2003). The first version of this textbook was written at this time.

Subsequently Rinck worked as physician-in-charge of one of the first two German government sponsored MR machines in Wiesbaden, Germany.

Between 1987 and 1994 he was head of Europe's biggest clinical and research MR facility – at that time – at the University of Trondheim, Norway. Between 1986 and 2012 he was also Adjunct Professor at the School of Medicine and Pharmacy of the University of Mons-Hainaut in Belgium.

Since 1982 Rinck is Chairman of the European Magnetic Resonance Forum, EMRF, and since 2008 President of the Council of The Round Table Foundation, TRTF.

He is also Chairman of the Selection Committees of the the Pro Academia Prize and of the European Magnetic Resonance Award.

Visiting Professorships: The Neurological Institute of Colombia. Bogotá, Colombia (1986); Charité University Hospital, Medical Faculty of Humboldt University, Berlin, Germany (1991-1992); et al.

President of the European Society for Magnetic Resonance in Medicine and Biology, 1985-1987; president of the annual meetings 1989, 2002. Scientific consultant and expert adviser to international organizations and foundations (among them WHO, European Commission, UNIDO, the Nobel Committee). Honorary, founding, or ordinary member of numerous professional and learned societies.

Among others, awards and prizes from the Alexander von Humboldt Foundation, Max Kade Foundation, NATO, European Commission, Fonds National de la Recherche Scientifique de Belgique, the Research Council of Norway, and German Research Society (DFG).

Author and/or editor of several books – not only scientific or medical – an e-learning website, numerous papers in refereed journals and communications to international scientific meetings; and since 1990 *Rinckside* (learned columns).

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