

Magnetism in Medicine

A Handbook

Edited by

Wilfried Andrä and Hannes Nowak

Second, Completely Revised and Extended Edition



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Wilfried Andrä and
Hannes Nowak*

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The Editors

Prof. Dr. Wilfried Andrä

Kernbergstrasse 39
07749 Jena
Germany

Dr. Hannes Nowak

Biomagnetic Center
Department of Neurology
Friedrich Schiller University
Erlanger Allee 101
07747 Jena
Germany

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Preface

Magnetism often has a slight overtone of being mysterious. This is probably caused by the surprisingly strong forces between magnets which everybody can experience with magnetic toys, magnet boards, or similar objects. A strange effect is the unique ability of magnetic fields to penetrate many substances without any attenuation. Though the physical basis of magnetism is well explored, the outsider usually does not know very much about the details and sometimes tends to overestimate the real possibilities provided by magnetism. Nevertheless, the limits of applications have not yet been reached. Considerable progress has taken place in medicine during recent years, and there is no reason to assume that this development has already come to an end.

Progress in medicine has often been initiated by the discoveries and results of research studies conducted among the various disciplines of natural science. One of the most famous examples to date is the discovery of a certain type of electromagnetic radiation, the X-ray, by Wilhelm Conrad Röntgen in 1895. In this case, the importance of the discovery with respect to medical applications was recognized immediately. Development was started and propelled by fruitful cooperation between both physicians and physicists. This teamwork is still very strong, and has led recently to the introduction of what is called electron beam tomography (EBT). In other cases – for example, that of nuclear magnetic resonance – the time taken between its discovery and subsequent application in medicine was longer. Sometimes, a new method has become established in clinical practice only after having passed through a long period of *in-vitro* investigations and preclinical trials. However, there are applications – for example, in biomagnetism – which could not be developed before other crucial parts (in this case the superconducting quantum interference device, SQUID, as a sensitive magnetic field detector) had been invented and further developed.

This cooperation between physicians, scientists, and engineers has proved itself in the past to be effective. It is a necessary condition for the continuing development of new methods or more sophisticated techniques and instruments. This is of particular relevance for the application of magnetism in medicine. Knowledge in this field is comparatively poor, even in the case of physicists. Specialists working in different fields of science and technology are, as a rule, not familiar with relevant problems in medicine, and as a consequence possible new ideas or solutions

to problems cannot be found until partners from different fields have been introduced to the physical and medical basis of this interdisciplinary topic.

One fundamental intention of this book is, therefore, to impart information about both the state of the art as well as the need for further progress with magnetism in medicine. This can only be done, within the ambit of this book, by means of reference to typical examples. A complete review of all existing contributions in this field would result in an edition of several volumes. We hope that the examples presented are suitable both for initiating cooperation between specialists already working on specific topics, and to encourage a response from newcomers who might contribute original ideas. In our opinion, the successful development of important methods such as functional magnetic resonance imaging (fMRI) and magnetic source imaging (MSI) in recent years is proof enough of the fact that even high-level technologies, which are already in existence, can be essentially improved and expanded as soon as interdisciplinary teams are involved. Moreover, there are also topics for which a level of knowledge has not yet been attained that would enable a “chain reaction” to start and thus accelerate further development. Here, in the language of physicists, a “critical mass” of interdisciplinary cooperating specialists has probably not been achieved.

During the years since the first edition of this book was published, many new developments have been made in the areas of medical research and clinical practice. Therefore, all contributions to the Second Edition have been updated, with most articles having been completely rewritten. Several new topics have been added, including: safety aspects of magnetic fields; fetal magnetography; new MRI techniques for cardiovascular imaging; clinical applications at ultra-high fields; interventional magnetic resonance imaging; concepts, systems, applications and new approaches in diagnostic and therapeutic MR mammography; monitoring of magnetic markers; remote-controlled drug delivery; and magnetic drug targeting.

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*Wilfried Andrä
Hannes Nowak*

List of Contributors

Christoph Alexiou

HNO-Klinik der Universität
Erlangen–Nürnberg
Waldstrasse 1
91054 Erlangen
Germany

Wilfried Andrä

Kernbergstrasse 39
07749 Jena
Germany

Michael Apel

Miltenyi Biotec GmbH
Friedrich-Ebert-Strasse 68
51429 Bergisch Gladbach
Germany

Peter Bachert

Arbeitsgruppe In-vivo-NMR-
Spektroskopie
Abteilung Medizinische Physik
in der Radiologie (E020)
German Cancer Research Center
Im Neuenheimer Feld 280
69120 Heidelberg
Germany

Roland Bammer

Department of Radiology
Lucas MRS Imaging Center
Stanford University Medical School
1201 Welch Road
Stanford, CA 94305
USA

Dimitri Berkov

INNOVENT e.V. Jena
Prüssingstrasse 27b
07745 Jena
Germany

Jürgen H. Bernhardt

Neureuther Strasse 19
80799 München
Germany

Gunnar Brix

Bundesamt für Strahlenschutz
Abteilung für Medizinische
Strahlenhygiene und Dosimetrie
Ingolstädter Landstrasse 1
85764 Oberschleißheim
Germany

John D.M. Campbell

Miltenyi Biotec Ltd.
Almac House
Church Lane, Bisley
Surrey GU24 9DR
United Kingdom

Donald W. Chakeres

Department of Radiology
College of Medicine and Public Health
Ohio State University Hospital
The Ohio State University
630 Means Hall
1654 Upham Drive
Columbus, OH 43210
USA

Michael Eiselt

Institute of Pathophysiology
Friedrich Schiller University
Nonnenplan 2
07743 Jena
Germany

David E. Farrell

Department of Physics
Case Western Reserve University
Cleveland, OH 44106
USA

Roland Fischer

Institut für Medizinische Biochemie
und Molekularbiologie II
Zentrum für Experimentelle Medizin
Universitätsklinikum Hamburg-
Eppendorf
Martinistrasse 52
20246 Hamburg
Germany

Minoru Fujiki

Neurosurgery
Department of Neurosurgical Science
Faculty of Medicine
Oita University
Japan

Peter Görnert

Innovent e.V.
Prüssingstrasse 27 B
07745 Jena
Germany

Urs Häfeli

Division of Pharmaceutics and
Biopharmaceutics
Faculty of Pharmaceutical Sciences
The University of British Columbia
2146 East Mall
Vancouver, B.C. V6T 1Z3
Canada

Birgit Hailer

Innere Medizin II
Philippusstift Essen
Hülsmannstrasse 17
45355 Essen
Germany

Jens Haueisen

Institute of Biomedical Engineering
and Informatics
TU Ilmenau
Gustav-Kirchhoff-Strasse 2
98693 Ilmenau
Germany

Uwe A.O. Heinlein

Miltenyi Biotec GmbH
Friedrich-Ebert-Strasse 68
51429 Bergisch Gladbach
Germany

Rudolf Hergt

Institut für Physikalische
Hochtechnologie e.V. Jena
Albert-Einstein-Strasse 9
07745 Jena
Germany

Karl-Heinz Herrmann

Institute of Diagnostic and
Interventional Radiology
Medical Physics
Friedrich Schiller University
Philosophenweg 3
07743 Jena
Germany

Jürgen Hennig

University Hospital Freiburg
 Department of Radiology
 Medical Physics
 Hugstetter Strasse 55
 79106 Freiburg
 Germany

Clemens Janz

Zartener Strasse 29
 79199 Kirchzarten
 Germany

Roland Jurgons

HNO-Klinik der Universität
 Erlangen–Nürnberg
 Waldstrasse 1
 91054 Erlangen
 Germany

Werner A. Kaiser

Institute of Diagnostic and
 Interventional Radiology
 Friedrich Schiller University
 Erlanger Allee 101
 07747 Jena
 Germany

Thomas R. Knösche

Max Planck Institute for Human
 Cognitive and Brain Sciences
 Muldenalweg 9
 04828 Bennewitz
 Germany

Olaf Kosch

PTB Berlin, FB 8.2 Biosignale
 Abbestrasse 2–12
 10587 Berlin
 Germany

Andrew C. Larson

Department of Radiology
 Northwestern University
 Feinberg School of Medicine
 448 E. Ontario Suite 700
 Chicago, IL 60611
 USA

Jonathan S. Lewin

The Russell H. Morgan Department of
 Radiology and Radiological Science
 School of Medicine
 Johns Hopkins University
 600 North Wolfe Street
 Baltimore, MD 21287
 USA

Debiao Li

Radiology and Biomedical Engineering
 Cardiovascular MR Research
 Northwestern University
 448 E. Ontario Suite 700
 Chicago, IL 60611
 USA

Stefan Miltenyi

Miltenyi Biotec GmbH
 Friedrich-Ebert-Strasse 68
 51429 Bergisch Gladbach
 Germany

Michael E. Moseley

Department of Radiology
 Lucas MRS Imaging Center
 Stanford University Medical School
 Stanford, CA 94305
 USA

Nobukazu Nakasato

Department of Neurosurgery
 Kohnan Hospital
 4-20-1 Nagamachi-Minami
 Taihaku-ku
 Sendai 982-8523
 Japan

Hannes Nowak

Biomagnetic Center
Department of Neurology
Friedrich Schiller University
Erlanger Allee 101
07747 Jena
Germany

Arnulf Oppelt

Schwedenstrasse 25
91080 Spardorf
Germany

Stefan O. R. Pfeleiderer

Institute of Diagnostic and
Interventional Radiology
Friedrich Schiller University
Erlanger Allee 101
07747 Jena
Germany

Jürgen R. Reichenbach

Institute of Diagnostic and
Interventional Radiology
Medical Physics
Friedrich Schiller University
Philosophenweg 3
07743 Jena
Germany

Hendryk Richtert

INNOVENT e.V.
Prüssingstrasse 27b
07745 Jena
Germany

Joachim Röther

Department of Neurology
Academic Teaching Hospital
Hannover Medical School
Friedrichstrasse 17
32427 Minden
Germany

Ekkehard Schleussner

Department of Obstetrics
Friedrich Schiller University
Bachstrasse 18
07743 Jena
Germany

Petra Schmalbrock

The Ohio State University
Department of Radiology
653 Means Hall
1654 Upham Drive
Columbus, OH 43210
USA

Jürgen Schmitz

Miltenyi Biotec GmbH
Friedrich-Ebert-Strasse 68
51429 Bergisch Gladbach
Germany

Uwe Schneider

Department of Obstetrics and
Gynaecology
Friedrich Schiller University
University Hospital
Bachstrasse 18
07743 Jena
Germany

Axel Schreiber

Siemens AG Medical Solutions
Marketing Magnetic Resonance
Karl-Schall-Strasse 6
91052 Erlangen
Germany

Oliver Speck

Universitätsklinikum Freiburg
Abt. Röntgendiagnostik, Medizin,
Physik
Hugstetter Strasse 55
79106 Freiburg
Germany

Gerhard Stroink

Department of Physics
Dalhousie University
Halifax, Nova Scotia B3H 3J5
Canada

Shoogo Ueno

Department of Biomedical
Engineering
Graduate School of Medicine
University of Tokyo
7-3-1 Hongo, Bunkyo-ku
Tokyo 113-0033
Japan

Peter Van Leeuwen

Entwicklungs- und Forschungs-
zentrum für Mikrotherapie
Universitätsstrasse 42
44799 Bochum
Germany

Clifford R. Weiss

The Russell H. Morgan Department of
Radiology and Radiological Science
School of Medicine
Johns Hopkins University
600 North Wolfe Street
Baltimore, MD 21287
USA

Christoph Werner

Scharnhorststrasse 2
07743 Jena
Germany

1

Introduction

1.1 The History of Magnetism in Medicine

Urs Häfeli

1.1.1 Origins

Although magnetic effects such as the “northern lights” in the northern hemisphere have been observed for thousands of years, it was not until the discovery of iron smelting, at around 1200 BC, that a body of knowledge on magnetism began to develop. The first effects of magnetism were observed when the smelted iron was brought close to the iron oxide in the chemical form of $\text{FeO}\cdot\text{Fe}_2\text{O}_3$ (Fe_3O_4), a natural iron ore which came to be known as lodestone or magnetite.

The origin of the term “magnetite” is unclear, but two explanations appear most frequently in the literature. In one of these, magnetite was named after the Greek shepherd Magnes, who discovered it when the nails on the soles of his shoes adhered to the ore. In the other explanation, magnetite was named after the ancient county of Magnesia in Asia Minor, where it was found in abundance.

The first treatise on magnetized needles and their properties (see Fig. 1.1) was presented by Petrus Peregrinus in 1289 (Peregrinus, 1269). This treatise clearly documented a number of magnetic properties including that: (1) magnetic forces act at a distance; (2) magnetic forces attract only magnetic materials; (3) like poles repel and unlike poles attract; and (4) north poles point north, and south poles south. Equipped with this knowledge, the medieval Europeans navigated the globe, discovering and conquering countries as they went.

Peregrinus, however, failed to note that the Earth itself is a magnet. Yet it was not until 1600 that this discovery was finally made by William Gilbert, a physician of Queen Elizabeth I. In order to arrive at this conclusion, Gilbert performed numerous experiments that separated hearsay from truth, documenting them in his book *De magnete* along with a summary of the knowledge of the time about magnetism and electricity (Gilbert, 1600). Gilbert’s systematic and scientific treatise is considered by many to be one of the first great works in science (Butterfield, 1991) (see Fig. 1.2).

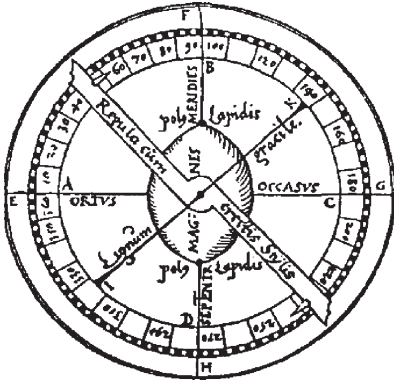


Fig. 1.1. One of Petrus Peregrinus' inventions is this "Astrolabium", an oval lodestone mounted inside a wooden box. The four points of the compass and 360 subunits were painted on the inside of the box. This instrument was placed in a bowl of water to determine the azimuth of the sun, for example, and the angle was read after the astrolabium had stopped moving.

1.1.2

First Medical Uses of Magnets

Thales of Miletus, the first Greek speculative scientist and astronomer (ca. 624–547 BC) was also the first to make a connection between man and magnet. He believed that the soul somehow produced motion and concluded that, as a magnet also produces motion in that it moves iron, it must also possess a soul. It is likely that this belief led to the many claims throughout history of the miraculous healing properties of the lodestone.

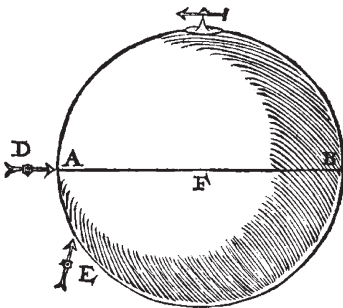


Fig. 1.2. The terrella (spherical lodestone), and the location of its poles from Gilbert's book *De Magnete*. The magnetic versorium (compass needle) on top of the sphere is pointing along a meridian circle; the versorium at D points directly to the center of the sphere and hence to the pole A, in contrast to the versorium at E.