Magnetism in Medicine

A Handbook

Edited by
Wilfried Andrä and Hannes Nowak

Second, Completely Revised and Extended Edition

WILEY-VCH Verlag GmbH & Co. KGaA

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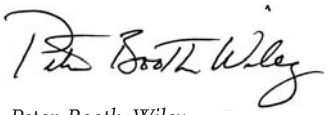

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Contents

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.

The editors wish to express their thanks to all authors for their kind cooperation. Our special thanks is given to Mario Liehr and Jürgen Reichenbach for their valuable cooperation in the editorial work. We are also grateful to the Biomagnetic Center at the Department of Neurology, University of Jena for kind support in the preparation of this book.

Jena, September 2006

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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 $FeO{\cdot}Fe_2O_3$ (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).

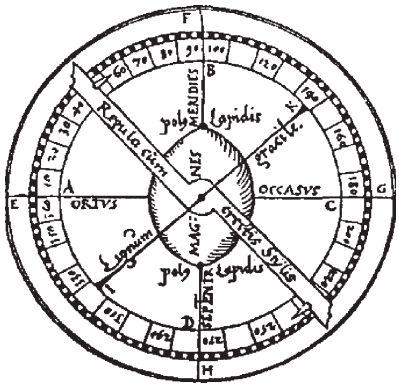

Fig. 1.1. One of Petrus Peregrinus' inventions is this "Astrolabium", an oval lodestone mounted inside a wooden box. The four points of the compass and 360 subunits were painted on the inside of the box. This instrument was placed in a bowl of water to determine the azimuth of the sun, for example, and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

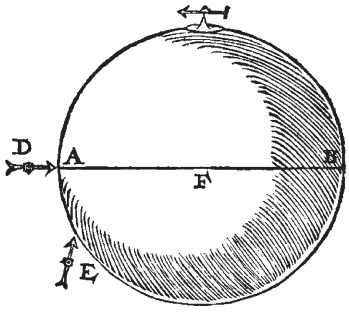

Fig. 1.2. The terrella (spherical lodestone), and the location of its poles from Gilbert's book *De Magnete*. The magnetic versorium (compass needle) on top of the sphere is pointing along a meridian circle; the versorium at D points directly to the center of the sphere and hence to the pole A, in contrast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