

HISTORY OF THE NEUROSCIENCES

Frank W. Stahnisch

The University of Calgary, Alberta, Canada & The University of California, Berkeley, U.S.A.

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Summary

The neurosciences have a long and fascinating history, one in which the bodily organs of the brain, spine, nerves, and eyes, and more recent theories about the soul and the mind have triggered the interest of natural philosophers, physicians, and researchers, as well as laypeople from ancient times to the contemporary modern period. As such, the history of the neurosciences incorporates wide perspectives from the history of philosophy and theology, the history of science and medicine, social, political, and cultural histories, as well as continued matters of economics and the health care benefit for human societies.

This chapter will introduce the reader to several major topics within the complex history of ideas, theories, and research approaches about the structure and functioning of the brain and spinal cord. It first explores the roots of our knowledge in the Ancient Egyptian, Greek, and Roman eras, while then following the medieval, early modern, and enlightenment discourses before giving an overview of the history of neuroscience in the modern centuries. The chapter focuses both on major contributors to contemporary knowledge as well as the succession and transformation of structural and

functional explanations of the brain and spinal cord, since they came to be aligned with individual regions, parts, and textures of the central and peripheral nervous systems.

Emphasis will be placed on some important topic fields within the neurosciences, and how research surrounding these fields has emerged, such as in areas of speech, memory, pain, vision, hearing, motor control, and a variety of other faculties of the mind and the brain. Throughout this chapter, considerable weight will be put on presenting the material in a very comprehensible way, as to accommodate the interested and informed lay readership, while also giving an overview of scholarly expertise about the historical development of the field in all its fascinating breadth and depth. The conclusions and perspectives presented at the end of this chapter offer a summarizing account of the long history that has informed the rise of the modern neurosciences and reflect briefly upon the directions of future research areas.

1. General Introduction

It has often been implied in research literature that the brain had always been an organ of primary concern for physicians and natural philosophers as the seat of the human soul and mind. While it is indeed true that most of the theories and concepts, which developed in the Western world since the classical Roman Period and the Medieval Ages, ascribed the brain such a pivotal place for the actions of the living body as well as the central organ for human spirituality and man's self-understanding with the advent of the Enlightenment Period, this had not continuously been the case: For the Ancient Egyptians, the totality and integrity of the entire human body as "involucrum" of the human spirit and soul was of much more importance than the endeavor to arrive at precise empirical knowledge of the isolated and delicate structures of the human brain itself. Ancient Greek natural philosophers and physicians emphasized rather the pivotal role of the human heart – as the seat of the soul (Greek *psyché*) – over that of the brain. In fact, most of them simply saw in the brain an organic cooling device for the physiological humors of the living animal and human bodies (instructive studies on this topic are: Von Staden 1989, Nutton 1995, Finger 2000, Guerrini 2003, Martensen 2004). A closer historiographical analysis therefore must start with an appreciation of the wide diversity and complexity of the philosophical and theoretical approaches to the physiological and cultural understandings of the brain and spinal cord. This account hence cannot support the view that the "brain", "neurophysiology," or even the "neurosciences" have always had the status and renown which they possess today. Rather than following such false conceptions – as this chapter will demonstrate and outline –, it is intellectually even more challenging to follow the rise and developments of scholarly, medical, and scientific traditions, which subsequently have led to the central status of the encompassing field of modern neuroscience. This way of approaching the topic will also help us to understand the foundations and the anthropological essence of modern-day societies, which base a large proportion of their public discourse on a rather new and dynamic scientific area, more so than had ever been the case in the history of Western civilizations (e.g. Neuburger 1989, Vidal 2011).

This chapter thus explores the long history of research and medico-scientific investigations into the brain and spinal cord. While such a study can hardly be all encompassing – given the vastness of the field – the central landmark developments and

transformations of the pursuit of knowledge in neuroscience are covered. This chapter intends to give an overview of the early foundations of brain anatomy and physiology, the emergence of the nerve and brain sciences since the Scientific Revolution of the Renaissance, and the innovative scientific accomplishments and methodologies since the 19th century. Additionally, it attempts to shed some more adequate light on the historical conditions that led to the development of the new research field of “neuroscience” – which rather appeared during the middle of the 20th century – and the socioeconomic, technological and military contexts in which the life sciences themselves became a “Big Science” (see: Coleman & Holmes 1988).

Furthermore, individual cultural and social backgrounds of the Western research endeavor in psychiatry, alienism, neurology, and later the neurosciences shall be investigated, giving particular attention to the way in which they were influenced by philosophical, spiritual, and cultural beliefs about the brain and spinal cord, held by members of the public as well as the neuroscientists themselves. In mapping out the diverging historical episodes and the various people and places in the long history of the neurosciences, the many side- and sub-developments, which occurred, and the alignment with other research fields cannot be sufficiently covered in a single chapter. Interested readers, however, who would like to know more about the changing cultural contexts of neurological and neuroscientific investigations, should refer to the more exhaustive accounts in the historiographical research literature (such as: Brazier 1988, Clarke & Jacyna 1992, Finger 2000, Hagner, 2000, Martensen 2004).

2. The Mind and Body in the Ancient World

Since the times of the Ancient Egyptians (c. 2800 to c. 700 B.C.), the brain has fascinated physicians, learned scholars, artists, and the public at large. Specific interpretations of the organ’s nature (e.g. a “faculty to cool the warmth of the body”, an “instrument of communicating with God”, a “thought-producing gland”, or an “information processing computer”, etc.) were incredibly diverse and included mystical and rational assumptions alike. However, even though the Egyptians possessed and developed a considerable knowledge of brain anatomy and certain medical nerve conditions, as described in the papyrus “Ebers” (circa 1530 B.C. – discovered in Luxor in 1873 A.D. by the German Egyptologist Georg Ebers, 1837-1898) along with descriptions of the heart, blood vessels, the brain, and urogenital organs, it must be kept in mind that this was largely knowledge derived by proxy. As far as we know today, the Ancient Egyptians did not develop and were not concerned with a “scientific” anatomical research tradition that was aimed at naturalistic descriptions of the human body or the pursuit of physiological experiments. Their anatomical observations and studies were largely a byproduct of the central ritual approach of embalming their dead and making observations during the application of the mummifying processes and technologies, which indeed were published in medical texts such as in the Ebers papyrus. Furthermore, Egyptian knowledge of the anatomy of the brain had its roots in the quasi-mythological surgical practice of trepanation, in which limited pieces of the skull were surgically removed to allow bad spirits and possessive demons to leave the human body. The number of trepanated skulls in the early history records about Egypt is nevertheless very small in comparison to earlier prehistoric finds and trepanated skulls

form the adjacent Assyrian, Babylonian, and East Asian civilizations, which may be due to rather external cultural influences (Arnott et al. 2003).

Likewise, knowledge of the nervous system in Ancient Greece and Rome was largely confined to external observations made in patients who had suffered from injuries in civil life or from war trauma. The strange behaviors of the “mad people” (Latin *furiosi*) gave rise to numerous medical, philosophical, and legal discussions about the role of the brain for man’s physiology, actions, and thought (Toohey 2004). Ancient medical and philosophical accounts of the actions of the human brain and physiology are hereby in several ways sensitive to the learned trajectories of thinking and speaking about the soul (Greek *psyché*). From comparatively modest origins in the “Illiad and Odyssey” of the Greek epic poet Homer (c. 8th century B.C.), the concepts of the “body” and “self” (represented as the life-breath and the soul; Greek *phrenes*) has received important semantic transformations since the pre-Socratic assumption of a unitary and elemental *psyché* from the 5th and 4th centuries B.C. (Nutton 1995).

One natural philosopher, however, stands out with regard to the contemporary scholarship, as Aristotle’s (384-322 B.C.) biological works were not purely confined to theoretical considerations, like those of many other physicians and philosophers of his time. As an accomplished animal dissector, Aristotle’s work was based on a multitude of comparative observations in shells, as well as in the eggs of snakes and chickens. In his books “On the Parts of Animals” and “A History of Animals”, he inferred from the anatomical organization of the body as to its physiological actions, and also described the central nervous system at various stages of morphological development (Aristotle 2002). As Aristotle believed in the pre-eminence of the brain as a bodily organ, he held the view that perception, imagination, and the capacity to move had to be essential features of both animal and human life (Van der Eijk 2000). In the physiological concepts and the medical culture of the ancient Greeks, the encompassing notions of “form” (Greek *morphé*) and fulfillment/perfection (Greek *entelecheia*), combined also with specific theories about the nerves, the brain, and finally the seat of the soul, as which Plato (c. 428/7-348/7 B.C.) had pivotally described the mind or soul in the “Republic” (in a tripartite model constituted of appetite, spirit, and reason) (Laidlaw 1996). This becomes further visible in Aristotle’s innovative theory of “hylomorphism” that was based on the assumption of a functional integration of the individual bodily organs as anatomical tools (Greek *èrgaleia*) by means of the dynamic structure and action of the souls of animals and humans. Particularly the assumption of *entelecheia* had herein been central to Aristotle’s discussion of the subject matter, as he exposed it in “On the Soul”, his major treatise that described the *psyché* as a principle or expression of corporeal actions and bodily unity, but that the soma remains lifeless without the psychological influences. Although Aristotle had moved away from the idealistic conceptions of the soul espoused by his predecessor Plato, he continued to retain a non-localized vision of the soul without becoming ensnared in dualistic complexities (Aristotle 2002).

In this respect, Greek natural philosophers assumed that higher animals which showed anatomical resemblances to man, would also have the same basic physiological *morphé* and hence could possess similar pathologies as human beings (Von Staden 1989). From here, however, emerged certain theoretical ambivalences, since Aristotle on the one

hand discussed the brain as an exceptional organ of the body, because of the assumed effect on the human *psyché*. On the other hand, Aristotle still adhered to the dominant cardiocentric physiological model that located (although not in all versions) many of the aspects of the “soul” in the heart – with its sensible palpitations, pains, and considerable phenomena of warmth in various emotional states –, a view which subsumed the brain as just another ordinary body part, like the liver, the intestines, or the lungs. However, some of the most vital aspects of the living soul were placed in the heart’s chambers, which in a sense is less surprising than the impression that a sense of “selfness” could be associated with the heart. Following this cardiocentric model – already advocated for by the Greek physicians of the 5th century B.C. following Hippocrates’ (c. 460-377) treatise “On the Sacred Disease” (c. 400 B.C.) as well as the medical works in “Concerning Nature” (c. 480 B.C.) of Alkmaion of Kroton (b. c. 510 B.C.) –, the brain’s role was rather seen as that of tempering “the heat and seething” of the heart.

Aristotle further held that human beings had “more sutures in the skull than any other animal, and males have more than females”. This observation underscored both the necessary size of the human brain as a cooling organ as well as the particular functional anatomy for the sake of ventilation, since the vapors were seen to leave the head through the bone sutures as outlets of the body (Finger 1994). The argument was made by both contemporary physicians and philosophers that the gross extension of the brain gave it a perfect form to cool the vapors of the heart as the many blood vessels present brought the vapors to the central organ (Clarke 1963).

Building on Aristotle’s natural history observations, Galen of Pergamon (129-c. 216 A.D.) – a Greek-born physician during the classical Roman period – began to dissect countless animal species, which he received from the Roman street markets, such as pigs and dogs, but also monkeys, and even a war elephant. After Galen had returned from Pergamon to Rome in 158 A.D. from his medical training abroad, he became the physician in charge of the gladiators in the Roman *Amphitheatrum flavium*. As the respective head physician, he provided nutritional advice and attended to the injuries of the gladiators (often head traumas and peripheral nerve wounds) which they had sustained during both exercises and arena battles for public audiences. In this work setting, Galen had also received the opportunity to develop new techniques of wound management, while sustaining the health and lives of the fighting gladiators – who were highly precious goods for their Ancient Roman owners. These collateral research opportunities also gave Galen the chance to emerge as one of the most established physicians of his time, an innovative observer, and as a most prolific writer on all topics of medicine, including the diseases and injuries of the nervous system (Nutton 1995).

3. Galenism, the Medieval Period, and the Four-Ventricle Doctrine

Galen’s observations on the nervous system were summarized in his ground-breaking book “On the Use of the Parts”, in which he discussed an early methodology of dissection and animal experimentation as a legitimate and valuable approach to gain basic medical knowledge about the brain and spinal cord. In fact, the nervous system strongly fascinated him and studies of its actions were overrepresented among Galen’s experimental observations. He based his own works on many of his predecessors – such as the famous Alexandrian School of human anatomy (as represented by Herophilus of

Chalkedon, c. 330/320-c. 260/250 B.C., and Erasistratos of Kos, c. 330-255/250 B.C.) – , which served as an important reference and starting point for most of his own observations and research assumptions concerning animal dissection and vivisection (von Staden 1989). For example, Galen closely observed the effects of ligaturing or cutting individual nerves and thereby conducted the most paradigmatic nerve experiment in ancient medicine, in which his target was the voice-related nerve; his experiment could be seen as a physical explanation for the loss of voice following injuries of the recurrent laryngeal nerve. Galen had initially conducted these experiments in order to study the process of breathing and by which means the rhythmic expansion of the lungs during the breathing process could be explained. During a vivisectional experiment in a pig, he suddenly realized that the pig immediately stopped squeaking after he had severed one specific pair of the nerves in its throat, but that it continued to breathe through the influence of other nerves (Nutton 1995).

When Galen reproduced his experiment in goats and dogs as further test animals, and could find very similar outcomes, he began to assume that he had found the “nerves of voice”, a discovery which has ever since been associated with his name as “Galen’s nerves” (Guerrini 2003). However, this was not just perceived as a basic finding, because Galen also compared the outcome of his experiments with the many clinical observations that he had made as a practicing surgeon for the higher classes of Roman society. For example, Galen had once operated on a young boy to remove some prominent glandular swellings; however, following the operation the patient had completely lost his voice due to the injury of these nerves. As can be expected, Galen – as Aristotle before – similarly took recourse to previous physiological theories, such as multi-part models of the soul (Aristotle: rational and irrational aspects; separating human from animal souls) and compared them with the outcome of his own animal experiments, to explain the pertinent clinical observations on this empirical basis. Galen’s experimental work in animals in conjunction with the clinical observations thus contributed considerably to the growing recognition of the importance of the nerves, while at the same time also his elaboration of the *pneuma* (particularly of the *pneuma psychikón*; Latin *spiritus animalis*), and its collection in the ventricles and distribution by the nerves, counted among the most valuable aspects of Galenic thought. Thereby, the Aristotelian “cooling action” of the brain was not entirely abandoned by Galen, but rather intriguingly incorporated into his physiological model of *pneuma* generation in the human body (Finger 2000).

The theoretical concepts, which followed from the tradition that Aristotle and Galen had founded, explained the actions of the human brain and spinal cord along with those of the entire living body as a hierarchically organized system. Based on Aristotle’s theory of differing forms of physiological action, the primitive *formae* – the *facultates naturales* (e.g. digestion, metabolism, and the creation of humors) – acted as the necessary basis for the higher *formae* – also known as the *facultates vitales* (such as the cooling or distribution of the humors in the body) – and the *facultates animales* (i.e. sensibility, appetite, and movement), which separated the higher animals and humans from plants and from non-living natural things. The *psyché*, finally, was seen as the ultimate cause of the living phenomena since it stimulated and directed the lower *facultates*. Galen himself, to a large extent, shared the Aristotelian physiological theories and only differed in so far as he placed the seat of the *psyché* (Latin *anima*) in

the brain; whereas, for Aristotle the brain had largely been a “cooling organ” that balanced the hot body humors emanating from the heart of living animals and humans. It is intriguing to note that based on the available evidence (ancient scriptures and autographs), the Aristotelian model of human physiology, in conjunction with the Hippocratic theory of the four humors, continued as the leading doctrine in Western thought on the brain and nerves throughout Medieval Times and that it also had a strong and lasting impact on medicine and natural history in the Early Modern Period (Tansey 1993). With respect to the historical transmission of these leading traditions in ancient natural history, also the contribution of the great Islamic-Arabic scholars must be emphasized since they kept these traditions alive and refined them too, as for example Rhazes (865-925 A.D.), who described the twelve cranial nerve pairs, Ibn-Sina (980-1037 A.D.), who gave an anatomical description of sensory and motor nerves along with a clinical differentiation of several neurological disease categories, or Ibn al-Nafis (1213-1288 A.D.), who established a detailed early model of psychosomatic interactions in physiology (Saliba 2007, Tibi & Savage-Smith 2009). Where one would have assumed that the effective surgical and ligaturing experiments of Galen would have had a much stronger influence on early neurophysiology and also a practical inclusion into surgical applications, this was not the case. In fact, Galen’s early neurophysiology was only fully received in the Northern European countries as late as the beginning of the 16th century. During this period, the French physician Jean Fernel (1497-1558) published the first complete version of “On the Use of the Parts” in a Latin translation – thus rendering it widely accessible to medical doctors, surgeons, and apothecaries –. Fernel thereby also introduced the term of “physiology” (French *physiologie*) into modern scientific language, while himself adopting the term from Galen (Rothschuh 1973). Yet wider challenges to the medical authorities and criticisms of the findings of the Ancient authors became rampant with the onset of the European Renaissance in science, literature, and the arts (please see the following section of this chapter).

Based upon Aristotle’s Gnostic theory of the four types of *morphé*, the influential Christian medieval philosopher Thomas Aquinas (1225-1274 A.D.) – who had been a priest and philosopher in the Dominican Order at the famous monasteries of Monte Cassino and Monte San Giovanni in Italy, developed a very decisive and long-lasting theoretical framework of the actions of the soul and the physiology of the brain, by building on the preceding doctrine of the localization of mental faculties that the Christian bishop and philosopher Nemesius of Emesa (b. c. 390) had established in his “On Human Nature” (4th century B.C.). It was employed by many church fathers and became later best known via its adoption by the Islamic physician Avicenna. This conceptual framework would become notorious as the “ventricular doctrine”, “cell doctrine,” or “cell theory” in the centuries to come, and to the popularity of which Aquinas had himself gainfully contributed to. With the ample authority of a “*Doctor universalis*” in the scholastic tradition – i.e. a real Philosophical Doctor, who had mastered both the natural sciences (as “natural philosophy”) and the humanities (particularly theology and philosophy, as still being a *prima philosophia* that stood hierarchically above the natural sciences and professions) –, Aquinas’ works were widely received at leading Medieval and Early Modern universities in Europe. He largely followed Aristotle, yet introduced a tripartheid of the soul (not just one *hylé* being the *psyché*) – bringing his doctrine of three ventricles in line – as an evidential form of natural philosophy – with the Christian religious dogma of the “unity of the

father, the son, and the holy spirit”. This theological doctrine found its correspondence in the “anterior chamber” of the ventricles, which was seen as responsible for the faculty of the imagination (pivotal for the scholastic upbringing of the Christian monk); the “middle chamber” that built the substrate for reason and estimation (later integrated with the “common sense”; Latin *sensus communis* – resembling the *psyché* in the Aristotelian and *koiné aisthisis* in the Galenic traditions); and finally the “posterior chamber”, which was seen as necessary for the faculties of active remembrance and passive memory (particularly of God and the human communication with the Divine sphere). Since the disintegration of the ventricles and faculties posed a serious philosophical problem to scholastic scholars, who understood the human subject as one, integrated with God, and not as three separate entities (please note: this argument should not be conflated with later, secular Enlightenment views about human individuality and the autonomy of reason), sometimes a fourth ventricle was mentioned. The additional fourth ventricle or “cell” became localized behind the vermis near the cerebellum to allow for the passage of the mental faculties to the nerves. It was thus perceived as a transitional structure or a conduit, which had been necessary for the communication of the common sense with the individual faculties localized in the other ventricles.

Some later Thomasian philosophers and theologians even promoted the idea that the human soul itself would have three faculties to correspond to. It was not uncommon for the Thomasian ventricular theory to be associated with certain objects from the natural world – based on the ancient theory of the sympathies and signatures (Greek/Latin *sympathiae* and *signaturae*). Scholastic drawings have been found, for example, which embed the ventricular physiologies in wider cosmologies of the microcosm (the human or animal body) in liaison with the macrocosm (the natural world of the universe) – claiming that the brain was associated with the planet Mars and the heart with the planet Venus as their respective astrological dispositions and meanings. It should also be noted that the ventricular or cell doctrine was not simply an element of scholastic natural philosophy, but that it transcended the Medieval Period right into Early Modern Times, represented, for instance, in the 16th century idea of the “imaginative eye” (Latin *Oculus imaginationis*), as it had been put forward by the British theosophist Robert Fludd (1574-1637). As a typical Renaissance man, Fludd was a medical doctor, natural philosopher, an astrologist, and a painter, who alluded to the ventricular doctrine from the perspectives of various human endeavors. In his widely read “Treatise on Metaphysics” Fludd claimed that the human brain and psyche were intricately linked to the astrological model of the macrocosm and microcosm, while the “imaginative eye” was located in the anterior chamber of the brain, just where Aquinas had placed the scholastic locus of the imagination. Over and above, scholars in history of science, psychology, and medicine have stated that the Medieval ventricular and cell doctrine had even dominated and intellectually influenced the phrenologists and anatomical localizationists of the late 18th century – thus speaking to the vivid parallel life of scientific ideas in their overall cultural context (Bell 2010).

Throughout the Middle Ages, the ancient knowledge acquired from animal experiments and the observations of human clinical phenomena continued to be the basis of Middle Eastern medical treatises and published works. This held likewise true for the writings in the Levant as well as in the Orient, exemplified greatly in the classical works of Ibn-Sina (known in the West as Avicenna). Ibn-Sina’s major compilatory work “The Canon

of Medicine”, which was subsequently rediscovered in the West during late-medieval times, preserved the preceding Greek tradition while also including new advances in anatomy, physiology, and vision theory, along with the practical introduction of early asylums emanating from the Arab-Islamic tradition (Tibi & Savage-Smith 2009). In this sense, “The Canon of Medicine” marked both an end-point to the great compilation traditions of the new medical schools and colleges in the Near-East as well as the beginning of a new, and in the best sense of the word, research tradition that Arab-Islamic physicians and philosophers began to create in the 10th and 11th centuries, when introducing a vast amount of new findings into the scholarship on the brain and nerves for the subsequent three hundred years (O’Sullivan 1996, Saliba 2007). To give some examples here: drawing on the earlier work of Ibn-Sina’s contemporary, Hunain Ibn Ishak (9th century A.D.), the 13th century Khalifa Ibn Abi Al Mahasin Al Halaby (from Aleppo) researched the optic tracts and even drew the first known cross-section of the brain in its anatomical connection to the eyes in his ground-breaking “Book of Sufficient Knowledge in Ophthalmology”. Ibn al-Haytham’s (10th and 11th centuries A.D.) “Optics”, written in Egypt in the first half of the 11th century, represented a physiological theory of vision that went considerably beyond the Greek works of Galen, Euclid (3rd century B.C.) and Ptolemy (c. 90-c. 168 A.D.). The famous diagram he drew of the two eyes as seen from above showed the principal tunics and the humors related to the optic nerves when connecting to the eyeballs; and it gave the complete description of an abstractly conceptualized brain. Furthermore, one of the earliest general and encompassing visualizations of the complete nervous system with the brain, spinal cord, and the peripheral nerves anatomically exposed – in an image that represented the human body from the back and the nerves shown in opaque watercolors –, was completed in 1488 by the scribe al-Hasan Ibn Ahmad (14th and 15th centuries A.D.), who worked in Isfahan, during the late Medieval and Early Modern Period (Russell 2010).

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Biographical Sketch

Frank W. Stahnisch received his Doctorate in History of Medicine from the Free University of Berlin, Germany. He is currently an Associate Professor at the University of Calgary (UofC), Alberta, Canada, where he is cross-appointed in the Department of History and the Department of Community Health Sciences. He also holds the Alberta Medical Foundation/Hannah Professorship in the History of Medicine and Health Care and is Chair of the UofC History of Medicine and Health Care Program and Coordinator of the History and Philosophy of Science Program. Currently, he is a Visiting Professor at the University of California at Berkeley, United States. As a historian of medicine and health care, his interests span the development of experimental physiology and laboratory medicine since the late 18th century (particularly France and Germany), the historical relationship between neurology/the neurosciences and the philosophy of the mind (focus on the German-speaking countries and North America), the relationship between clinical neuroscience and public mental health (particularly Canada and the United States), the historical epistemology of the life sciences (18th to 21st centuries), and the longer history of visualization practices in medicine and health care. He is the author of *Ideas in Action* (2003); co-editor (with Florian Steger) of *Medizin, Geschichte und Geschlecht* (2005); co-editor (with Ulrich Schoenherr and Antonio Bergua) of *Albert Neissers 'Stereoskopischer Medicinischer Atlas'* (2006); co-editor (with Heijko Bauer) of *Bild und Gestalt* (2007), and co-editor (with Sylwia Werner and Claus Zittel) of *Ludwik Fleck – Denkstile und Tatsachen: Gesammelte Schriften und Zeugnisse* (2011). His most recent monograph is *Medicine, Life and Function: Experimental Strategies and Medical Modernity at the Intersection of Pathology and Physiology* (2012).