

Armin K. Thron

Vascular Anatomy of the Spinal Cord

Radioanatomy as the Key to
Diagnosis and Treatment

Second Edition

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With collaboration of
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Foreword

Between 1977 and 1979, Armin Thron, at that time a young general radiologist, taught himself neuroradiology. He and the upcoming *crème de la crème* in neurology (H. J. v. Büdingen, P. Clarenbach, J. Dichgans, Ch. Diener, V. Dietz, H.-J. Freund, V. Koenig, G. Leopold, K.-H. Mauritz, J. Noth, G. Oepen, G.-M. von Reutern, U. Thoden, U. Weitbrecht) belonged to the famous Department of Neurology and Neurophysiology at the University of Freiburg, Germany. Being a neurosurgical consultant, I had the chance to follow Armin's metamorphosis from a common radiologist to a neuroradiologist in this steam boiler of alpha-types led by Professor Richard Jung.

And yet again, from 1979 to 1987, Armin Thron provided a large number of neurologists and neurosurgeons (E.H. Grote, W. Hassler, H. Steinmetz, J. Zentner) with his neuroradiological knowledge as assistant professor under the directorship of Karsten Voigt in the Neuroradiological Department at the University of Tübingen. It was there that he started his experimental and clinical investigations about the vascular blood supply and vascular diseases of the spinal cord, thus creating the basis for the first edition of his book.

After fulfilling necessary criteria to obtain a leading position, Professor Armin Thron spent the rest of his professional life, from 1987 to 2010, at the University Hospital of the RWTH Aachen University. From 1989 until our respective retirements, we cooperated well: he as the leading neuroradiologist, me as his neurosurgical counterpart.

Every day from 7:30 to 8:30 a.m., we held our neurosurgical-neuroradiological conference where Armin and his compatriots taught us neuroradiology and we got the chance to defend our surgical misadventures and the sometimes controversial indications for surgical interventions. To my personal disappointment, many of my neurosurgical co-workers identified these conferences as the most defining part of their training.

Just as at Freiburg and Tübingen, at the University Hospital in Aachen, Armin again trained many upcoming leading neurosurgeons (H. Bertalanffy, V. Coenen, F.H. Hans, A. Harders, V. Rohde, K. Schmieder, U. Sure, E. Uhl, J. Warnke).

Armin and I were both born in 1945 and belong to the 68-generation. Therefore, it was not surprising that we first had to define our professional and team positions in Aachen before we could become friends and also enjoy a good and successful professional time together.

For this new version of his book, Professor Thron spent a lot of his sparse private time as a pensioner in order to help his readers. But as is typical for Armin, he is fully dedicated to the cause of his work without regard for the achievement of personal recognition.

Thanks to Armin's favourite topic, spinal vascular disease, we had the chance to come across numerous interesting cases and most fortunately could help many of the concerned patients owing to our fruitful neuroradiological-neurosurgical cooperation. Therefore, I highly recommend that one consider this book not only as a basic textbook but also as a key to microsurgical treatments of spinal vascular disorders.

Aachen, Germany
September 2015

Joachim Gilsbach

Preface

The excitement which the subject represents to us lies in the fact that buildings with what is in principle an identical function exist in such a variety of diverse forms

Bernd and Hilla Bechers

The idea for a treatise on the radiological anatomy of superficial and deep spinal cord blood vessels evolved from daily routine neuroradiological work in the early 1980s at the University of Tübingen. The topic was not induced but promoted by guest stays at hospitals in Paris, especially at the Neuroradiology Department of Lariboisière Hospital. Jean-Jacques Merland, the head of the department at that time, and his predecessor René Djindjian were highly renowned for practising selective spinal angiography at the highest level. This met very well with my long-lasting interest in diseases of the spinal cord.

Progress in selective angiography of the spinal cord in suspected disease of vascular origin demanded an advanced understanding of spinal cord blood vessel anatomy and its variations. Parallel to this development, progress in neurosurgery and especially the rapidly developing endovascular treatments in interventional neuroradiology improved our knowledge in this field and broadened the spectrum of treatment options. Significantly ameliorated disease classifications could be established, reflecting an improved understanding of pathogenetic aspects of vascular diseases like in cases of arteriovenous malformations, dural arteriovenous fistulas or vascular tumours of spine and spinal cord.

The first version of this book, *Vascular Anatomy of the Spinal Cord*, published in 1988, was a monograph, bearing the subtitle *Neuroradiological Investigations and Clinical Syndromes*. Thus, it was subdivided into an anatomical part with post-mortem examinations of arteries, capillaries and veins of the spinal cord in normal and pathological conditions and in a clinical section. The latter reflected the progress in diagnostic imaging mentioned above, mainly in selective digital subtraction angiography (DSA). Computed tomography (CT) was not very helpful for intraspinal details at that time and magnetic resonance imaging (MRI) was in its modest beginnings, at least concerning imaging of the spinal cord. Only two figures of this book from 1988 illustrate a clinical case example using MRI. Myelography using water-soluble contrast media was still the established standard technique to outline the structures within the dural sac.

The rapid technical progress in non-invasive imaging techniques in the fields of MRI, MR angiography or modern CT technologies, but also upgraded DSA units with higher spatial/contrast resolution, offered new detailed insights into the intraspinal compartments.

Consequently the diagnostic methods illustrating the clinical part of the treatise published in 1988 are only of historical value today with the exception of selective angiography. Not only for this reason, we have abstained from including this type of clinical section in this second edition. We concentrate on what we consider fundamental in this context: vascular anatomy and its correlation with spinal angiography in normal and pathological conditions.

This field of basic classical anatomy has maintained its essential importance. It has been established for a long time and has not been the subject of fast and dramatic modifications. The basic principles are generally well known, but the knowledge of details depends on whether physicians are able to make use of them for patient care or scientific purposes. But, to give an

example, details about the blood vessels and the blood circulation within and around the spinal cord could be neglected to a certain degree as long as nobody was in need of this knowledge; and as long as nobody was able to perform successful diagnostic and therapeutic interventions based on this knowledge. But during the last 25 years this situation has changed substantially both for diagnostic and therapeutic modalities.

Nevertheless, a clear conception of the vascular radioanatomy of the spinal cord and its variations remains an obvious challenge for many physicians, even for those working in disciplines which are involved in patients suffering from spinal cord diseases. This is the reason why the anatomical knowledge presented in the previous edition has maintained if not augmented its significance.

We have tried to simplify the basic principles by using schemes and graphics to facilitate learning and training by an improved didactic presentation. Anatomical evaluations of angiographic findings in vascular malformations and special notes on dangerous pitfalls or examination requirements are included in order to address some important problems in the clinical application of blood vessel anatomy.

The many details presented in the microangiogram section mainly address those concerned with either scientific questions or with invasive therapeutic techniques and who are familiar with the interpretation of radioanatomic findings.

A comprehensive description of medullary vascular syndromes would be beyond the scope of this treatise. It would require a different approach with more interdisciplinary contributions from physiologists, neurologists, neuroradiologists, neurosurgeons and neuropathologists.

Aachen, Germany
January 2015

Armin K. Thron

Acknowledgement

The first group of radioanatomical investigations on the spinal cord were performed at the Department of Neuroradiology, University of Tübingen, in the 1980s. It is to the department's head at that time, Prof. Dr. K. Voigt, that I express my sincere gratitude for stimulating and supervising my initial scientific projects, and for constant support.

Encouraged by Prof. Dr. W. Dauber from the Department of Anatomy of the University of Tübingen, we made the first steps to inspect the anatomy of spinal cord blood vessels and to test techniques of radiographic work-up of the contrast-injected specimens.

Prof. Dr. J. Peiffer, a neuropathologist, and his collaborators from the Institute for Brain Research at the University of Tübingen also gave valuable support and kindly provided their laboratory facilities for us.

After I had changed to the University Hospital of Aachen in 1987 to become Head of the Neuroradiological Department, additional anatomical, functional and clinical studies were planned and could be carried out during the 1990s thanks to excellent support from the Institute of Neuropathology. Therefore I owe special thanks to Prof. Dr. J. Schröder, the former Head of this Institute, for not only providing laboratory facilities for us but also for participating in cooperative investigations initiated by our department.

Special thanks are further expressed to Mrs. Virginia Müller and Prof. Dr. H. Steinmetz for the translation of the first edition of the book and Springer International Publishing AG for copy-editing the final manuscript of the second edition.

Furthermore, I would like to thank Prof. Dr. J. J. Merland (Hopital Lariboisière, Paris) and Prof. Dr. B. Kendall (National Hospital, Queens Square, London) for the inspiration gained through their work and for the fruitful exchange of ideas and friendly personal contact.

To accomplish a scientific project resulting in a monograph and a textbook like the one presented, you need help from many people.

This is why I want to list those who practically assisted in one way or another in the realization of this project with my grateful thanks.

Dr. Christine Rossberg

At the time of the initial neuroanatomical study she worked at the Neuropathological Department of the University of Marburg (Head Prof. Dr. H. D. Mennel). I owe special thanks to her for removing and preparing most of the post-mortem specimens which we were able to evaluate macro- and microangiographically. Her contribution included the first radiographic documentation of the prepared specimen. She was a member of the Department of Neuroradiology in Tübingen in the early 1980s before she changed to the Department of Neuropathology in Marburg. She died in October 2001. Without her practical and professional assistance, the post-mortem anatomical study could not have been realized, at least not with this quality of specimen preparations.

Prof. Dr. Angel Mironow

Comprehensive post-mortem and clinical investigations are impossible without the assistance of colleagues and the exchange of views and experiences on an advanced level. I owe special thanks to my former colleague Prof. Dr. A. Mironow for his initial help in conceptual considerations and post-mortem preparations.

Walter Korr

He is a former graphic artist of the University Clinic of the RWTH Aachen University.

The concept for the second edition of the book followed the ambitious plan to make the book useful not only as an instructive atlas for scientific purposes but at the same time as a textbook or a teaching file for the neuro-specialities. Therefore I was very happy to meet him and to benefit from his special abilities. His professional help is evident in the computer graphic design of the diagrams in this book, which I had conceptualized and outlined for didactic purposes over several years.

In the context of our continuous research on anatomy, clinical imaging and endovascular treatment of vascular diseases of the spine and spinal cord at the University Clinic of Aachen, I owe sincere thanks to the following colleagues and collaborators:

Assistant professor Dr. Michael Mull, and Prof. Dr. Timo Krings

For their highly qualified everyday support and especially for their keen interest in the basic scientific and advanced clinical imaging projects of the department. Guided by our primary principles of intellectual honesty in research and patient safety in interventional procedures they helped to maintain a high level of competence and patient confidence in diagnostic and interventional challenges over many years.

Dr. Juergen Otto, and Dr. Tibor Jacobs

Were medical students working on a thesis for a doctorate in medicine under my guidance. They elaborated topics on morphological and functional anatomy of spinal cord veins.

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About the Author



Armin K. Thron is Professor of Neuroradiology. Until March 2010 he was the Head of the Department of Neuroradiology at the University Clinic of the University of Technology Aachen, Germany. From 1996 to 1999 he was the President of the German Society of Neuroradiology and from 1996 to 2002 he was the President of the Professional Association of German Neuroradiologists. He was member of the Board of the European Society of Neuroradiology from 1993 to 1996 and President of the XXIX Congress of the European Society of Neuroradiology 2004 in Aachen, Germany. Prof. Thron has a special interest in spinal diseases and vascular diseases of the spinal cord. He is author of various textbook contributions concerning mainly diagnostic and interventional neuroradiology.

Because of progress in microneurosurgery and interventional neuroradiology, intramedullary lesions have become more and more accessible and treatable. Unfortunately, a lack of knowledge about spinal vascular anatomy is evident in many conferences with neurologists and sometimes even with neurosurgeons and neuroradiologists. This lack of knowledge might be a reason for unsatisfactory clinical results in the treatment of spinal vascular diseases by invasive therapeutic techniques. Furthermore, magnetic resonance imaging (MRI) and magnetic resonance angiography (MRA) of blood vessels in and around the spinal cord have substantially improved. To provide a correct anatomical interpretation of the demonstrated blood vessels, knowledge of the anatomy of spinal cord blood vessels is the first prerequisite.

1.1 Historical Background

1.1.1 Previous Studies

Our limited knowledge about the physiology and pathology of the spinal blood supply contrasts with anatomical descriptions of the spinal vascular system from as early as the end of the nineteenth century by Adamkiewicz (1881, 1882) and, with a precision that has hardly been achieved since, by Kadyi (1889). Earlier studies, such as those by Duret (1873) and Ross (1880), were less defined, incomplete and unsystematic. Until about the middle of the twentieth century, the spinal vascular system was seldom the object of thorough anatomical research. However, one must mention the comprehensive works of Tureen (1938) and Suh and Alexander (1939), who called back to mind the results of Kadyi (1889).

According to these previous investigations, one ventral and two dorsal arterial trunks supply the spinal cord. They

originate at the cranial end by feeders from the distal segment of the vertebral arteries, as well as by a varying number of lateral feeders of different calibre entering with the nerve roots at different levels. These radicular arteries originate from segmental arteries or homologous vessels.

On the basis of this anatomical knowledge, Bolton (1939) carried out injection studies to examine blood flow direction and vascularization territories of the medulla. As of 1950, the interest in problems of spinal vascular supply was stimulated by progress and new questions raised by clinical work. Some examples of these are neurological complications following surgery on the aorta and spinal column (Adams and van Geertruyden 1956; Hogan and Romanul 1966; Adams 1984), neurological syndromes of assumed vascular origin (Kalm 1953; Zülch 1954, 1976; Gruner and Lapresle 1962) and the spinal vascular malformations that had become diagnosable with the introduction of clinical spinal angiography (Djindjian et al. 1963, 1970; Di Chiro et al. 1967; Doppman et al. 1969). These clinical challenges have led to an expansion and deepening of our knowledge. Noteworthy are the studies of Gillilan (1958, 1970), of Lazorthes (1972) and co-workers (1958, 1962, 1966, 1971, 1973), Noeske (1958), Roll (1958), Perese and Fracasso (1959), Clemens and v. Quast (1960), Corbin (1961), Houdart et al. (1965), Romanes (1965), Hassler (1966), Jellinger and Neumayer (1972), Mannen (1966), Turnbull et al. (1966), Fazio and Agnoli (1970), Manelfe et al. (1972), Pisco (1972), Dommissie (1975), Tveten (1976a, b, c), Crock and Yoshizawa (1977), Moes and Maillot (1981), Crock et al. (1986). Except for a few studies by authors such as Kadyi (1889), Suh and Alexander (1939), Clemens and v. Quast (1960) and Crock and Yoshizawa (1977), the arterial system was more extensively, if not exclusively, examined. Venous anatomy was focussed upon in the studies of v. Quast (1961) as well as Gillilan (1970) and in the detailed treatise of Moes and Maillot (1981) about the superficial veins of the human spinal cord. Breschet (1828–1832) and later on Batson (1957)