
The Development of Spinal Cord Anatomy

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Key Words

Spinal cord anatomy • Spinal nuclei • Tracts • Nerve roots

Abstract

A panel illustrating spinal cord injury in *The Dying Lioness* in the British Museum dates to 650 BC. This paper outlines the subsequent progression of knowledge of the anatomy of the spinal cord. The animal dissections of Galen are considered because his deductions persisted through the Dark Ages until the late 18th century. Anatomy advanced gradually to yield discoveries of the complex tracts and grey matter elements of the cord and their functions. Amongst many distinguished exponents, the works of Blasius, Huber, Vicq d'Azyr and Stilling are emphasised. Copyright © 2008 S. Karger AG, Basel

The salient discoveries of the complex tracts and grey matter elements of the cord is the aim of this summary. It contains brief selective background notes of those who discovered these structures – many of whose names are eponymously attached to them. Blasius, Huber, Vicq d'Azyr and Stilling are, somewhat arbitrarily emphasised for the originality of their work at difficult times when advancement of knowledge of the cord appears in retrospect to have been stagnant.

Beginnings in Mesopotamia and Greece

An early example of spinal cord injury can be seen in *The Dying Lioness* in the British Museum (No. 00032586001), a stone panel from the Assyrian North Palace of Assurbanipal, c 650 BC. It depicts clearly a lioness injured by arrows traversing her back and spine that is attempting to crawl forwards, dragging her evidently paralysed hind limbs. The Hippocratic physician, Herophilus (325–260 BC) was born in Chalcedon and worked at the Alexandrian school of Medicine. He first demonstrated the cord was the caudal extension of the hind-brain naming it the 'spinal cord,' stating 'the neura that make voluntary motion possible have their origin in the cerebrum (enkephalos) and spinal marrow'. Little was known of the function of the spinal cord before Galen's anatomical studies conducted in the 2nd century AD. Galen (130–200 AD) carried out dissection and vivisection of animals and provided anatomical details of the vertebral column, spinal cord and nerve roots.

He divided surgically parts of the spinal cord, showing that motor and sensory function below the lesion were lost, the pattern depending on the size and location of the section. He thereby deduced that the function of the nerves was mediated by 'the animal spirits', originating in the brain. They passed through the nerves to the 'feeling and moving parts', but how they did so he could not decide. Galen described: 'the cord like a river rising from its source, extended from the brain, continuously sending

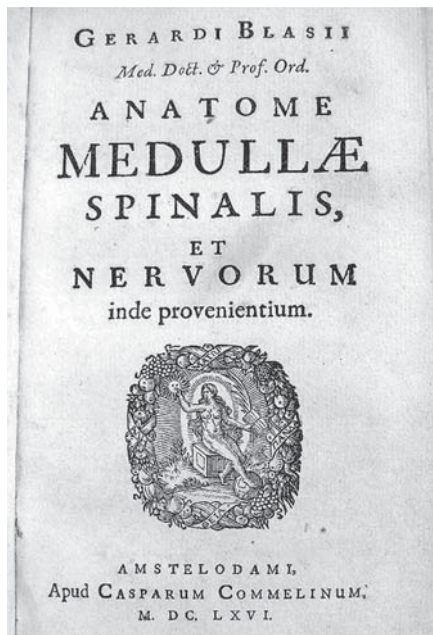


Fig. 1. Title page of *Anatome medullae spinalis* (1666). From Blasius [3].

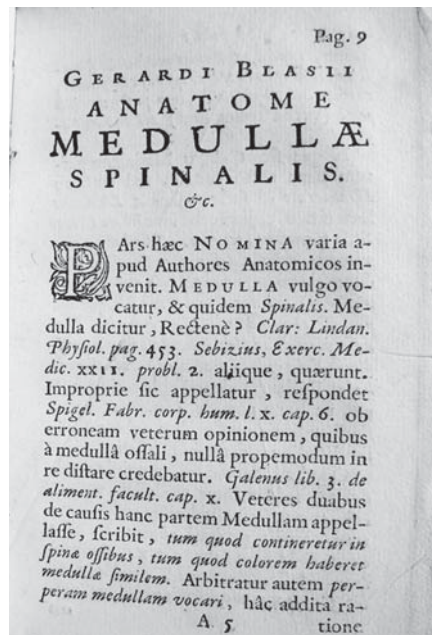


Fig. 2. First page, *Anatome medullae spinalis* (1666), criticising past opinions. From Blasius [3].

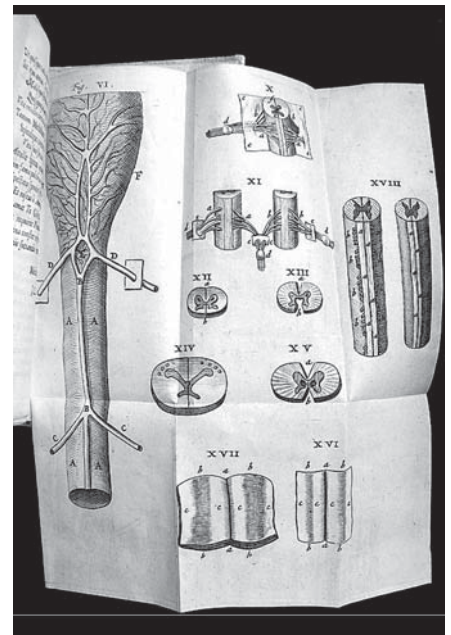


Fig. 3. Blasius' illustrations of the cord and medulla showing vertebral and anterior spinal arteries, nerve roots, and H-shaped grey matter. From Blasius [3].

forth a nerve channel to each of the parts that it meets, through which both sensation and motion are conveyed...'. He recorded the clinical consequences of transection and tuberculosis.

The Dark Ages

During the medieval period (700–1500 AD), Avicenna (980–1037 AD) noted the spinal roots were 'like a spray' and pointed out 'God placed the spinal cord into a bony hard channel called the spine to protect it from injury'. But for centuries almost nothing of note was added to Galen's account of spinal cord structure. After the dark ages, Vesalius (1514–1564), likewise added little new to Galen's work on the cord. Charles Estienne (1503–1564), known as Stephanus, did describe the central canal, and in *La dissection de parties du corps* described the case of a spinal cord cyst as early as 1546 [1]. It will be seen that the ancients had to deduce the functions of the cord by crude observations of injury and disease. The anatomical approach was crucial to advancement, but since techniques were necessarily primitive original studies were sparse, and Galen's signal observations of anatomy were mainly based on animal dissections.

Gerard Blasius

In 1666, coincident with the Great Fire of London, a Dutch anatomist Gerard Blaes (aka Blasius; 1625–1692), published a remarkable compendium: *Anatome Medullae Spinalis Nervorum*. It contained comparative descriptions in great detail of the anatomy of 119 animals; 78 were shown in excellent illustrations (fig. 1–3). Blasius was well known for his thorough knowledge of embryology, natural history and anatomical curiosities. His anatomy was surprisingly accurate and detailed, providing new facts, but he had no access to the more sophisticated histological technology of later eras. Blasius demonstrated the anterior and posterior spinal roots and separated the grey and white matter of the cord. He differentiated the grey and white matter of the cord (fig. 3). He was the first to illustrate clearly the H shape of grey matter in a cross-section of the spinal cord [2]. His subsequent comparative anatomy was published in *Anatome animalium, terrestrium variorum* in 1681 [3].

Blasius was Professor of Medicine at Amsterdam. According to Cole, Blasius' work: 'may be accepted as the first comprehensive manual of comparative anatomy based on the original researches of a working anatomist, and is a valuable starting point for the history of zootomy' [4].

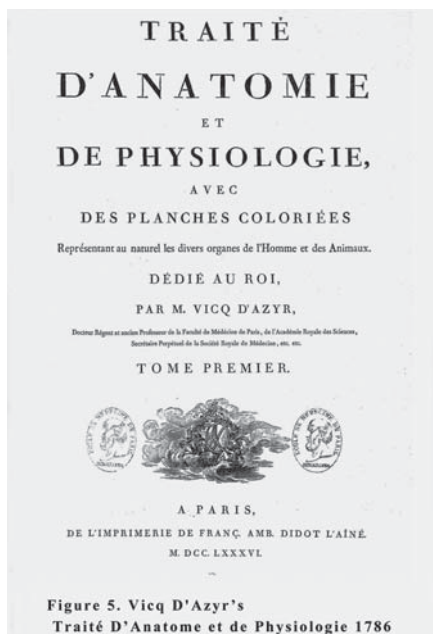


Figure 5. Vicq D'Azyr's *Traité D'Anatomie et de Physiologie* 1786

Fig. 4. Vicq D'Azyr's *Traité D'Anatomie et de Physiologie* (1786). From Clarke and O'Malley [5].

18th Century: Nerve Bundles and Decussations

In 1709, some 40 years after Blasius's work, Domenico Mistichelli (1675–1715) from Pisa confirmed the pyramidal decussation [1, 5, 6] first described by Aretaeus [1, p. 17]. Francois Pourfour du Petit (1664–1741) in 1710 gave a brief but accurate account of the cord's internal structure and also described the pyramidal decussation, relating it to contralateral motor paralysis of cerebral lesions.

Johann Jacob Huber (1707–1778), the Swiss physician from Basel, was an anatomist and botanist of distinction, professor of anatomy and surgery at Kassel. He gave an even more accurate description of the cord, and its component divisions in *De medulla spinalis speciatim de nervis ab ea provenientius commentatio cum adjunctis iconibus* (Gottingen, Vandenhoeck, 1741). A major step forward was his account of the spinal roots and dentate ligaments and he suggested that the cord be divided into columns.

Felix Vicq d'Azyr (1748–1794) the French anatomist, elaborated these findings. He was born in Valognes, Normandy, and amongst many distinguished accomplishments became in 1789, physician to Queen Marie-Antoinette. He held the chair of anatomy at the Paris Faculty of Medicine, and published numerous human and ani-

mal anatomy treatises. In 1789, he was perpetual secretary of La Société Royale de Médecine created in 1776. On his instigation, this society published *Nouveau plan de constitution pour la médecine* (1790): the first medical reforms of the Revolution. Vicq d'Azyr, using coronal and sagittal sections of alcohol-fixed brain and cord to facilitate dissection, made the crucial discovery that established the arrangement of the fibre bundles of the spinal cord into a posterior and two lateral columns and a white anterior commissure (fig. 4) [7]. (He also described the locus coeruleus and the mamillothalamic tract, which bear his name.)

19th Century: Tracts and Nuclei

The 19th century yielded many investigations of the position and course of the different tracts or fasciculi in the cord [1, 5]. Amongst a host of such anatomical studies we can highlight some landmarks. Luigi Rolando (1773–1831) fled from his native Turin during the Napoleonic invasion of the country to go to Florence, where he learned anatomical dissection, drawing, and engraving; he studied the appearance of nervous tissue under the microscope. Later he went to Sardinia where he described the substantia gelatinosa of the dorsal grey matter in 1809, and observed the precentral and postcentral gyri on either side of the great central fissure. In Sardinia for 12 years, he became Professor of 'Theoricopractical' Medicine at Sassari, finally returning to Turin as Professor of Anatomy.

Until 1811 no differentiation of function had been made in relation to the spinal nerve roots. Sir Charles Bell (1774–1842) [1, 8] in 1811 showed: 'stimulation of the anterior portion of the spinal marrow (spinal roots) convulsed animals more certainly than injury to the posterior portions'.

He deduced that the anterior roots of the spinal nerves were dedicated to transmission of motor impulses from the brain to the limbs and trunk, whereas the posterior roots selectively carry sensory impulses to the brain from the periphery.

The mode of conduction of the nerve impulse was, however, still a mystery. Isaac Newton (1642–1727), believed vibrations in the 'ether' within the nerves mediated sensation. Luigi Galvani (1737–1798), in the late 18th century showed that electric phenomena existed in the nerves and muscles of sheep, identical to the electricity recognised in atmospheric storms and to the 'artificial' electricity produced by rubbing amber [9]. In the 1830s,

Carlo Matteuci (1811–1868), demonstrated the intrinsic nature of animal electricity when he showed he could stimulate a muscle to contract when its nerve was laid on another actively contracting muscle. And, in 1827 Leopold Nobili (1787–1835), using a galvanometer detected a flow of current up the body of a flayed frog from muscles towards the spinal cord; Richard Caton (1842–1926), confirmed this in 1877.

Burdach (1776–1847), showed the fasciculus cuneatus in 1826 [10, 11]. Ludwig Türck (1810–1868) described the ventral corticospinal tract in 1849, and in 1853, divided the cord into six pathways or tracts: two anterior, two lateral, and two posterior [6]. Charles Édouard Brown-Séquard (1817–1894) [12] carried out hemisection of the cord in cold-blooded vertebrates and mammals, showing contralateral loss of pain and temperature sensation, with ipsilateral corticospinal and posterior column loss. This formed the basis of his doctoral thesis in 1846 [13], and of subsequent papers. These clinical findings led to the term Brown-Séquard syndrome. Five years later, Lockhart Clarke (1817–1880), [14] distinguished the lateral from the medial cuneate nucleus, and identified for the first time the nucleus intermediolateralis, the ‘posterior vesicular column’ now known as Clarke’s column [15, 16]. Heinrich Lissauer (1861–1891) in 1886, demonstrated the tractus dorsolateralis [17] – the poorly myelinated fibres capping the apex of the posterior horn. Friedrich Goll, Swiss anatomist, (1829–1903) in 1868 described the fasciculus gracilis; Flechsig (1847–1929) in 1876 demonstrated the dorsal spinocerebellar tract; Bastian and Sir William Gowers (1845–1915) [18] delineated the ventral spinocerebellar tract, and von Monakow (1853–1930), in 1910 [19] the rubrospinal tract.

But relating function to structure was still elusive. Little new was added after Charles Bell (1774–1842) [8, 20] and Magendie [21] distinguished sensory from motor nerves and separated motor from sensory function within the spinal nerves.

Benedikt Stilling’s Microtome

The crucial anatomical advance was from naked eye to microscopic examination. It was made possible by an invaluable tool, the microtome, devised by the surgeon, Benedikt Stilling (1810–1879) in January 1842 [22]. This enabled him to cut the frozen, or alcohol-hardened spinal cord into thin sections and examine them, unstained, with the microscope. Stilling noted that the grey matter was both the anatomical and physiological ‘nucleus’ of

the cord. He observed the distinction between grey and white matter, the columnar tracts, and that fibres radiated from the grey matter horns to the anterior white matter. Stilling’s technique was the cornerstone of the investigation of spinal cord by histology.

Born in Hessen-Nassau, Stilling read Medicine at Marburg qualifying in 1832. But for a Jew, academic posts were not available. He took the position of Landgerichts-Wundarzt (surgeon to the law courts) in Kassel in 1833. But, the authorities believed that Jews should not be allowed such elevated preferment and therefore transferred him to an inferior post in Eiterfeld. Stilling found this unacceptable and resigned, to devote his energies to a thriving private surgical practice. At his own expense he pursued academic work travelling to Paris to visit Magendie, and Amussat who instructed him in surgery of the urethra. He visited and worked in Italy, England and Vienna with Claude Bernard, Brown-Séquard, Rayer, and Charcot. He continually returned to Kassel, where he died.

In 1832, Stilling homografted the cornea of a rabbit. He was said to be an exceptionally competent gynaecological and urogenital surgeon, performing ovariectomy by the extraperitoneal route to avoid bleeding. In 1840, he published his best known work on neurology [23], in which he first investigated the vasomotor nerves. He also published histological investigations of the pons (named after Costanzo Varoli, Italian 16th century surgeon) and the structure of the cerebellum, as well as contributing to the histology of the spinal cord [24, 25].

Brown Séquard (1817–1894) performed lateral hemisections of the dog’s spinal cord. His description [26] of ipsilateral paralysis and hyperaesthesia with loss of sensation in the contralateral limb was based on numerous animal experiments and human cases with pathological confirmation. His experiments showed that the principal conduction of sensation in the cord was in the central grey matter and anterior columns, rather than in the conventionally accepted posterior columns.

In 1851, Lockhart Clarke used spirits of wine and turpentine as fixatives that hardened preparations for better sectioning to disclose the cord’s internal structure. Franz Nissl (1860–1919) developed a stain for neurones and revealed the chromophilic neuronal granules that bear his name in 1894 [27]. Camillo Golgi (1843–1926) developed the first silver impregnation methods to stain neural tissue and Ramón y Cajal (1852–1934) further enhanced the heavy metal impregnation of neurones. These and other invaluable staining techniques allowed demonstration of the pattern of branching of axons and dendrites and neuronal interconnections.

Relating Anatomy to Physiology

Different experimental techniques slowly yielded fragments of the cord's functional jigsaw puzzle. Paul Flechsig (1847–1929) observed that the tracts in the nervous system acquire myelin in a definite sequence, and fibres belonging to various functional systems became myelinated at approximately the same time they become functional; he therefore concluded that the acquisition of myelin determined the initiation of function [28]. But the explanation was unsatisfactory since animal foetuses show varied and complex movements before myelination began. It later appeared that there was a critical diameter for the initiation of myelin production ranging from 1–2 μm [29].

Joseph Jules Dejerine (1849–1917) described radicular myotomes and dermatomes [30, 31], the somatotopy and connections of the pyramidal tracts, as well as the lateral and ventral spinothalamic tracts [30]. He demonstrated the lateral and anterior spinothalamic tracts (the 'faisceau en croissant' de Dejerine).

The accomplished neurologist, Henry Charlton Bastian (1837–1915), demonstrated in 1890, 4 patients who had lost tendon jerks below a cervical cord transection [32], and this formed the basis of 'Bastian's law': a transverse lesion of the spinal cord above the lumbar enlargement results in abolition of the tendon reflexes of the low-

er extremities.' Born in Truro, Bastian was physician to University College, and the National Hospital, Queen Square, in London. In later life he became obsessed with the notion of the *abiogenetic* origin of life.

The 20th century began with the brilliant work of Santiago Ramón y Cajal and Camillo Golgi who illuminated the dark recesses of fine neural structure, sharing the Nobel Prize in 1906. They were succeeded by Sir Charles Scott Sherrington (1857–1952) and Lord Edgar Douglas Adrian (1889–1977) who shared the Nobel Prize in 1932. Sherrington elucidated the 'integrative action of the nervous system'. Adrian clarified the nature of the nervous impulses and the physical basis of sensation.

Bror Rexed (1914–2002), anatomist at Uppsala, was invited by Ragnar Granit to have a laboratory at the Nobel Institute, where between 1952 and 1954 he divided the grey matter of the cord into 10 (I–X) laminae based on groupings of neuronal size and distribution. Each contained functionally distinct neurones and axonal projections. This clarified the functionally incomplete studies of some 19th century anatomists [33]. There followed many advances in clinical, radiological and surgical techniques and scientific studies of spinal cord disease, physiology, and localization. However, many aspects, particularly those relating to immunopathology, neural growth and regeneration are still not well understood.

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