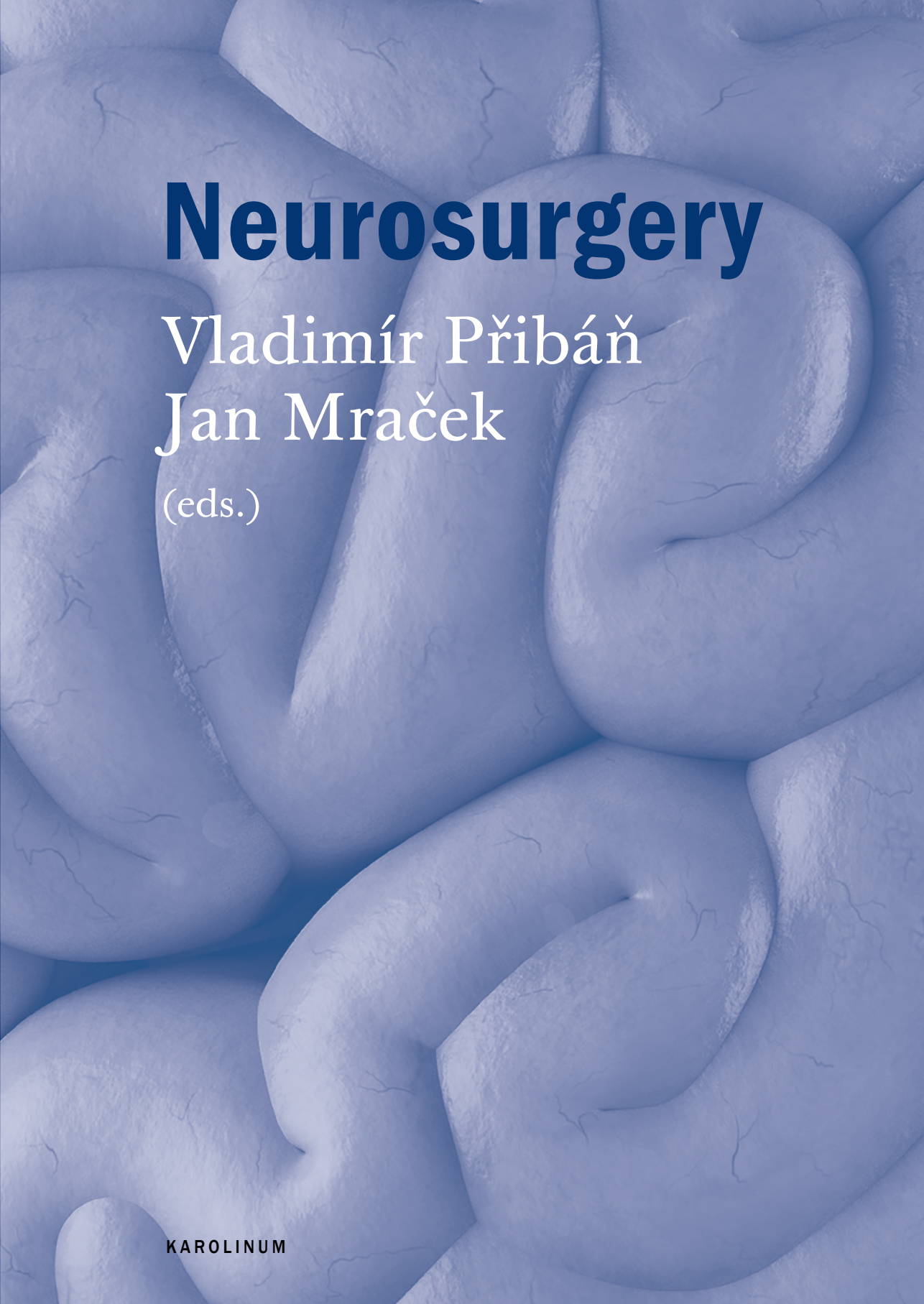

Neurosurgery

Vladimír Přibáň
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Translated from the Czech original Vladimír Přibáň, Jan Mraček (ed.), Neurochirurgie, Karolinum 2022, second revised edition, by Gerry Vickers, Jitka Šedová, and Jan Lodin.

This publication was published with the support of the Ministry of Education, Youth and Sports and the Czech Recovery Plan within the project Transformation for Universities at CU (reg. No. NPO_UK_MSMT-16602/2022).

Funded by the European Union
NextGenerationEU

CZECH RECOVERY PLAN

MINISTRY OF EDUCATION, YOUTH AND SPORTS

Published by Charles University
Karolinum Press
Prague 2023
Edited by Jana Jindrová
Cover and layout by Zdeněk Ziegler
Typeset by Karolinum Press
First English edition

The original manuscript was reviewed by Vladimír Beneš (Department of Neurosurgery, Second Faculty of Medicine, Charles University and University Hospital Motol), Jiří Fiedler (Department of Neurosurgery, Hospital České Budějovice), and Lumír Hrabálek (Department of Neurosurgery, Faculty of Medicine and Dentistry, Palacký University Olomouc and University Hospital Olomouc).

ISBN 978-80-246-5688-5
ISBN 978-80-246-5689-2 (pdf)

Charles University
Karolinum Press

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Contents

Preface

This neurosurgery textbook forms the basic material for teaching this specialised field at the Faculty of Medicine in Pilsen. Together with lectures and practical exercises, they form a basic information summary needed to prepare for the neurosurgery examination. We have endeavoured to create an up-to-date text containing a wealth of graphic documentation that will provide information not only to medical students, but also to young residents in the field of neurosurgery.

The book follows neurosurgical scripts that were edited by the late Luděk Navrátil, MD, PhD. The original chapters of which Navrátil was the key author, have been updated and expanded, and they form the backbone of the general part of the book. We therefore dedicate this textbook to the memory of our colleague and co-author.

We would also like to mention our mentors who accompanied us through the field.

Last but not least, we thank our spouses, partners and families, without whose understanding and patience we would not be able to fully devote ourselves to our field.

Vladimír Přibáň

Abbreviations

3D	three-dimensional
5-ALA	5-aminolevulinic acid
A1	initial segment of the anterior cerebral artery (pre-communicating segment)
ACA	anterior cerebral artery
ACTH	adrenocorticotropic hormone
ADC	apparent diffusion coefficient (diffusion weighted image sequence on MR)
AG	angiography
AIDS	acquired immune deficiency syndrome
AOD	atlantooccipital dislocation
AP	anteroposterior X-ray projection
APV	artificial pulmonary ventilation
ATB	antibiotics
ATP	adenosine triphosphate
AVM	arteriovenous malformation
BA	basilar artery
BAEP	brainstem auditory evoked potentials
BBB	blood-brain barrier
BCNU	bis-chloroethylnitrosourea (carmustine)
BP	blood pressure
BTP	brain tumour polyposis
c	constant
C, Th, L, S	abbreviations for the cervical, thoracic, lumbar, sacral spine
CBF	cerebral blood flow
CCF	carotid-cavernous fistula
CEA	carotid endarterectomy
$CMRO_2$	cerebral metabolic rate of oxygen
CNS	central nervous system
CO2	carbon dioxide
CPP	cerebral perfusion pressure
CRP	C-reactive protein
CS	central sulcus
CST	corticospinal tract
CT angiography	examination of the vascular bed on CT
CT	computed tomography
CT-PMG	CT perimyelography
CUSA	cavitron ultrasonic surgical aspirator
CVA	cerebrovascular accident (stroke)
CVP	central venous pressure
CVR	cerebrovascular resistance
DAI	diffuse axonal injury

DAVF	dural arteriovenous fistula
DBS	deep brain stimulation
DIND	delayed ischaemic neurological deficit
DM	dura mater
DNA	deoxyribonucleic acid
DNET	dysembryoplastic neuroepithelial tumour
DOPA	dihydroxyphenylalanine
DREZ	dorsal root entry zone
DSA	digital subtraction angiography
DTI	diffusion tensor imaging (tractography)
DWI	diffusion weighted MR imaging
EBV	Epstein–Barr virus
EEG	electroencephalography
EMG	electromyography
ENT	otorhinolaryngology
EP	evoked potentials
ERPs	endogenous evoked potentials (event related potentials)
$ETCO_2$	end-tidal carbon dioxide
FB	frontobasal
FBSS	failed back surgery syndrome
FCH	fluorocholine
FDG	fluorodeoxyglucose
FET	fluoroethyltyrosine
FiO_2	fraction of inhaled oxygen
FLAIR MRI	sequence of T2 weighted MR image
FLT	fluorothymidine
fMRI	functional MRI
FT-MRI	MRI fibre tractography
GCS	Glasgow Coma Scale
GM	glioblastoma multiforme
Gy	grey, unit of ionizing radiation dose
HASTE	MR sequence (half-fourier acquisition single-shot turbo spin echo imaging)
HCG	human chorionic gonadotropin
HIV	human immunodeficiency virus
HU	Hounsfield units
IM	intramuscular
IV	intravenous
ICA	internal carotid artery
ICG angiography	fluorescent angiography intraoperatively using IV application of ICG
ICG	indocyanine green
ICP	intracranial pressure
ICU	intensive care unit
iCVA	ischaemic cerebral vascular accident (stroke)
IDD	intrathecal drug delivery
IDH	isocitrate dehydrogenase
IOM	intraoperative electrophysiological monitoring
kPA	kilopascal
LE	lower extremities
LMWH	low molecular weight heparin
M1	initial segment of the middle cerebral artery
MAC	minimum alveolar concentration
MALT	mucosa associated lymphoid tissue
MAP	mean arterial pressure
MCA	middle cerebral artery
MGMT	methyl-guanine-methyltransferase
microRNA	microribonucleic acid
MMA	middle meningeal artery

mmHg	millimetres of mercury (torr)
MRA	MR angiography
MRI	magnetic resonance imaging
mRS	modified Rankine score
MRSA	methicillin resistant *Staphylococcus aureus*
MVD	microvascular decompression
N_2O	nitrous oxide (laughing gas)
NaF	sodium chloride
NF	neurofibromatosis
NGS	next generation sequencing
NIRS	near-infrared spectroscopy
NOAC	non-vitamin K oral anticoagulants
nTMS	navigated transcranial magnetic stimulation
p.o.	oral administration
PAG	brain panangiography
PBSC	peripheral blood stem cells
PCA	posterior cerebral artery
pCO_2	partial pressure of carbon dioxide
P-comm	posterior communicating artery
PCV	procarbazine, CCNU (lomustine), vincristine
PEEK	polyetheretherketone
PEEP	positive end-expiratory pressure
PET	positron emission tomography
PET/CT	hybrid imaging combining PET and CT
PET/MRI	hybrid imaging combining PET and MRI
PFO	patent foramen ovale
PICA	posterior inferior cerebellar artery
PitNET	pituitary neuroendocrine tumour
PNC	penicillin
PNET	primitive neuroectoderm tumour
PNO	pneumothorax
PNS	peripheral nervous system
pO_2	partial pressure of oxygen
$PtiO_2$	partial oxygen pressure in brain tissue
REZ	root entry/exit zone (transition zone of the cranial nerve)
RIND	reversible ischaemic neurologic deficit
RT	radiotherapy
rTPA	recombinant tissue plasminogen activator
SAH	subarachnoid haemorrhage
SCS	spinal cord stimulation
SEP	somatosensory evoked potentials
SHH	sonic hedgehog
SjO_2	jugular venous oxygen saturation
SM	Spetzler–Martin classification
SPECT	single photon emission computed tomography
spf.	superficial
SpO_2	peripheral oxygen saturation
STA	superficial temporal artery
STH	somatotropic hormone
T1	MR sequence
T2	MR sequence
TBI	traumatic brain injury
TCD	transcranial dopplerometry
TEE	transesophageal echocardiography
TIA	transient ischaemic attack
TIVA	total intravenous anaesthesia
TM	temporal muscle

TNF-α	tumour necrosis factor alpha
TNM	tumour nodes metastases
TOF	train of four (method of monitoring the depth of muscle relaxation)
TSH	thyroid stimulating hormone (thyrotropin)
TTF	tumour treating fields
UE	upper extremities
VEP	visual evoked potentials
VHL	von Hippel Lindau
Vb	blood volume
Vcsf	cerebrospinal fluid volume
Vbt	brain tissue volume
WBRT	whole brain radiation therapy
WHO	World Health Organization
WNT	wingless and WNT-1 signalling pathways

A GENERAL PART

A1 Introduction and Historical Notes

Neurosurgery encompasses surgical treatment of diseases of the central nervous system, peripheral nerves, and their supporting structures – mainly the spine.

The first historical records date to the Neolithic period, i.e. 5000–7000 BC. Discoveries of healed trepanation burr holes, which demonstrate successful patient recovery, have been documented in Lozère, France. The highest number of discoveries associated with burr hole surgery has been found in Peru and dates back to the pre-Inca (approximately 3000 BC) and later Inca period. The motivations to perform surgery were partially religious, however indirect signs of intracranial hypertension on the skulls also suggest an effort of seeking medical relief. Of these two groups, what stands out is utilizing trepanation to treat epilepsy. The Edwin Smith Papyrus from ancient Egypt documents the knowledge of the physician **Imhotep**, and includes a description of a complete spinal cord injury, brain injury, and motor pathways. However, brain surgery in the form of trepanation was not performed in the ancient civilisations of Egypt, Mesopotamia, India, or China.

Ancient Greece, represented by **Hippocrates** (ca. 400 BC), is considered the cradle of modern medicine. Hippocrates considered the brain to be the seat of mental activity and described brain and spinal cord injuries. He mastered the trepanation technique, which he performed for epilepsy, headaches, and fractures.

The Greek physician **Galen**, living in Rome in the 2nd century AD, viewed the liver and heart as centres of the human organism. In his opinion, the liver represented the place of blood formation as well as metabolic and nutritional control. He considered the heart to be the source of innate heat, which it distributed throughout the body. According to Galen, the brain was an organ of thought and the centre of perception, movement, and speech. He performed operations on live animals and demonstrated paralysis after spinal cord injury. Throughout his career, he performed several ground-breaking operations, including brain surgery. In Roman times, basic principles of antisepsis and asepsis were applied, however these were later forgotten for many centuries. The teaching of medicine at universities was influenced by Galen's texts until the 17th century.

Significant personas of the Renaissance period include **Andreas Vesalius** (1515–1564), who laid the foundations of modern anatomy. The 7th book of his magnum

opus *De humani corporis fabrica* provides a detailed description of the brain, including the ventricular system. **Ambroise Paré** (1500–1590), the pioneer of vascular ligation, lived and worked in the same period as Vesalius. Both were royal surgeons, Vesalius at the Spanish court and Paré at the French court. They encountered each other at the bedside of the mortally wounded King Henry II of France, who had suffered a subdural haematoma in a knight tournament. Paré was the treating physician and Vesalius was invited to consult.

Jan Jesenský (1562–1621) was a famous anatomist and surgeon of the Czech lands. He performed the first public autopsy in 1600, was the rector of Charles University and the personal physician of Emperor Rudolf II. He was later executed for participating in the Estates Uprising.

The roots of modern surgery date back to the 19th and early 20th century. General surgery developed and was divided into individual subfields. The first pillar was the introduction of general anaesthesia. The first ether anaesthesia was administered by **W. Morton** on October 16, 1846 at Boston General Hospital for a patient with a mandibular tumour. The place where the surgery was performed (which was in fact the auditorium) is now open to the public.

Another milestone was the introduction of antisepsis and asepsis. The first steps using the disinfecting properties of carbolic acid (phenol) were taken by **Lister**. This was followed by the introduction of rubber surgical gloves by **Halsted** and sterilisation of surgical instruments. The third pillar was the discovery of blood groups by **Landsteiner** resulting in the availability of safe blood transfusions. These three foundation stones enabled surgery to flourish and specialize. Other comparable groundbreaking events also occurred in the 20th century, such as the discovery of antibiotics and direct imaging of the brain and spinal cord via CT and MRI.

Going back to the 19th century, neurosurgical operations would be performed as part of major surgeries. In 1879 in Glasgow, **Macewen** operated a frontal meningioma and in 1885 he performed the "first" laminectomy for spinal cord compression. In fact, the first laminectomy had been performed and documented and published by the Czech professor **Karel Maydl** in 1882, but it was unfortunately forgotten. In 1887 **Victor Horsley** extirpated a spinal meningioma from the spinal cord of an officer with severe preoperative paraparesis. This resulted in the patient regaining his ability to walk.

The true founding father of neurosurgery was **Harvey Cushing** (1869–1939). He was a student of Halsted at Johns Hopkins in Baltimore and was involved in neurosurgery from the outset. He visited famous European greats of the time (Billroth in Vienna, Horsley in London) and concluded that, without the strict separation of neurosurgery as a specialized field, no progress could be made. The only positive thing about the trip to Europe was probably his internship under the renowned Dr Kocher in Basel. It was in the laboratory of physiology that he studied intracranial hypertension, following which he devoted his whole life to the topic. Cushing significantly developed our knowledge of the pathophysiology and surgery of pituitary tumours. Indeed,

Harvey Cushing (1869–1939)

one syndrome bears his name to this day. During World War I he dedicated himself to brain traumatology on the battlefield. His main contribution was in the field of meningeal tumours (meningiomas), and in the technical field, he played a role in the formation of bipolar coagulation and clips (silver clamps) as a means of stopping arterial cerebral haemorrhage.

Walter Dandy (1886–1946) was his student and later became his rival. In the early 1920s he introduced diagnostic ventriculography. It was based on the principal of inserting a catheter into the ventricle and aspirating a certain volume of cerebrospinal fluid. Air would then be insufflated into the ventricles, and the ventricular system could then be displayed on an X-ray. Distortions, compressions, and other morphological changes indirectly reflected pathologies of interest, such as tumours. Dandy had other priorities: he contributed to the understanding of the pathophysiology and therapy of hydrocephalus, he performed surgeries within the cerebellopontine angle (schwannomas), he transsected trigeminal fibres in essential neuralgia (juxtapontine rhizotomy) and operated ventricular pathologies. He was the first to directly operate a cerebral aneurysm, and in 1937 he occluded the neck of an aneurysm using a Cushing clip.

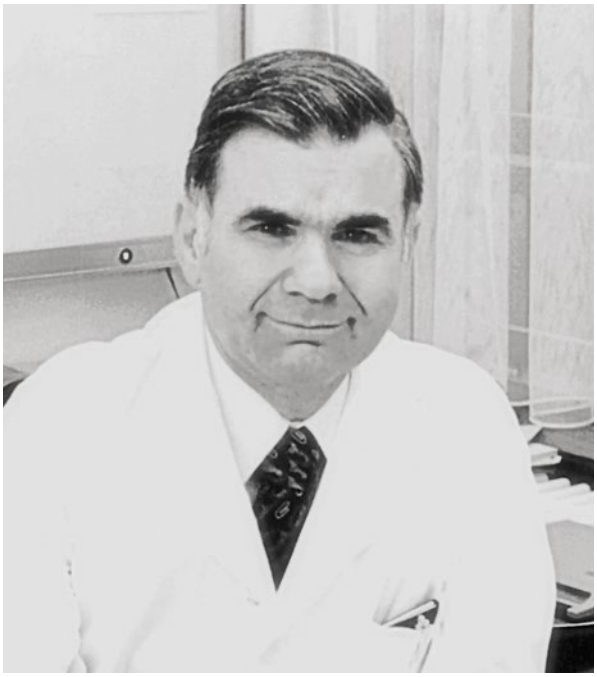
The introduction of brain angiography by **Egaz Moniz** in 1927 was a significant diagnostic breakthrough. Pathologies of the vascular bed (aneurysms, AVM) were visualized directly, vascular tumours demonstrated pathological vascularisation and the other lesions manifested indirectly by distortion of the natural course of the ves-

sels. Currently, angiography holds an important position not only in diagnosis but also in the treatment of vascular diseases of the brain.

The first direct imaging of the brain was made possible by computed tomography (CT) in the 1970s. **G. N. Hounsfield** and **A. McLeod Cormack** were quite rightly awarded the Nobel Prize in 1979. To the present day, this remains a key diagnostic method in brain traumatology, ischaemic and haemorrhagic stroke, and it partially replaced invasive angiography in the diagnosis of vascular lesions. Magnetic resonance imaging played a similar revolutionary role in diagnostics, and the 2003 Nobel Prize was awarded to **P. C. Lauterbur** and **P. Mansfield** for their contribution in this field.

Neurosurgical techniques underwent a revolution in the early 1970s. After extensive work on cadavers **M. G. Yasargil** (1925) came up with a new concept of the anatomy of the brain, cerebral vessels, and cisterns. Together with the introduction of the operating microscope, its application brought about the era of microneurosurgery, which continues to this day. If Cushing is the father of neurosurgery, then Yasargil is the father of modern neurosurgery. These are the two most important personalities in the history of neurosurgery in general.

The last decade of the 20th century brought the first use of the endoscope in surgeries of the pituitary and ventricular region, Leksell's Gamma Knife, and the explosive development of interventional neuroradiology. This resulted in neurosurgical subspecialisation. The basic subspecialisations of neurosurgery include: neurotraumatology, vascular neurosurgery, oncological neurosurgery, spinal neurosurgery, peripheral nerve neurosurgery, stereotactic and functional neurosurgery and paediatric neurosurgery.



Gazi Yasargil (1925)

Zdeněk Kunc (1908–1985)

Zdeněk Mraček (1930–2022)

In the Czech lands, neurosurgical procedures were performed as a part of major surgery long after the passing of Cushing. This logically delayed development of this field. The founders of Czech neurosurgery were **Rudolf Petr** (1912–2003) in Hradec Králové and **Zdeněk Kunc** (1908–1985) in Prague-Střešovice. The Department of Neurosurgery in Hradec was established in 1954, the department in Prague in 1956 and the clinic in 1959.

The neurosurgical department in Pilsen was established within the surgical clinic in 1956. The first chief physician was **Quido Ledinský**. As assistant to Professor Petr, he represented the Hradec Králové school of neurosurgery. Professor **Zdeněk Mraček** became his pupil and long-term successor. He also spent several years with Professor Kunc and is thus considered an "amphibian" of both schools of neurosurgery. Under his leadership, neurosurgery developed as a whole, especially neurotraumatology. He was a tireless promoter of decompressive craniectomy and was the first neurosurgeon in the Czech Republic to describe moyamoya. He performed pain surgery and modified Sjöquist's tractotomy and became the first elected mayor of Pilsen following the Velvet Revolution.

Mraček was succeeded by chief physician **Milan Choc**, who became the founder of modern neurosurgery. He introduced microsurgery of the brain and spinal cord surgery, he was the first to perform stabilisation procedures of the spine and was known for his surgical approaches to aneurysms of the vertebrobasilar basin. During his period as chief physician, neurosurgery was moved to a new location in Lochotín. This department acquired a neurosurgical ICU, an electrophysiological laboratory, a speech therapy laboratory and sufficient bed capacity. In 2012, **Vladimír Přibáň** took over the role of chief of the department. In 2015, the department acquired the status of a clinic.

A2 Examination Procedures in Neurosurgery

A2.1 CLINICAL EXAMINATION

In neurosurgery, obtaining a medical history is the first step of the clinical examination. Data is acquired from the patient, their companions or paramedics who provided pre-hospital treatment. We inquire about specific symptoms, their severity, speed of occurrence, accompanying circumstances, details of the accident, etc. For example, a sudden acute headache that has not previously occurred, often associated with nausea, can be the result of cerebral aneurysm rupture and subarachnoid haemorrhage.

Determining the injury timeline and the development of the consciousness disorder has major therapeutic and forensic consequences. For example, determining whether a patient primarily became unconscious and fell, or primarily fell and then lost consciousness is key.

Knowledge of associated conditions such as pharmacological treatment is important. For example, anticoagulant or antiplatelet medications can lead to the progression of intracranial haemorrhage with fatal clinical consequences. Immediate diagnosis of a coagulation disorder and its subsequent urgent correction is of utmost importance in the successful treatment of spontaneous and traumatic intracranial haemorrhage.

The clinical examination in neurosurgery does not differ significantly from a standard neurological examination. Emphasis is put mainly on **assessing the state of consciousness**. The **Glasgow Coma Scale** (GCS) is used to evaluate quantitative disorders of consciousness (Table A2.1). We assess eye, verbal, and motor responses. A patient with unimpaired consciousness scores 15 points on this scale, while an unconscious patient scores 8 points or less. Deep coma without response to external stimuli has the lowest score of 3 points. In bilateral cortico-subcortical lesions with diencephalic involvement, unconsciousness is usually associated with **decortication rigidity** (decortication syndrome). This is characterized by abnormal tonic flexion in the upper extremities and extension on the lower extremities (Fig. A2.1). Contrary to this, **decerebration rigidity** is characterized by abnormal extension of the upper extremities in the elbows with flexion and pronation in the wrist, and extension of the lower extremities. In the developed state, it is accompanied by a tonic contraction

Table A2.1 Glasgow Coma Scale (GCS)

Eye opening response	Spontaneously	**4**
	To speech	**3**
	To pain	**2**
	No response	**1**
Verbal response	Oriented to time, place, and person	**5**
	Confused	**4**
	Inappropriate words	**3**
	Incomprehensible sounds	**2**
	No response	**1**
Motor response	Obeys commands	**6**
	Moves to localised pain	**5**
	Flexion withdrawal from pain	**4**
	Abnormal flexion (decorticate)	**3**
	Abnormal extension (decerebrate)	**2**
	No response	**1**
Total score	Clear consciousness	**15**
	Disorder of consciousness	**9–14**
	Unconsciousness (coma)	**3–8**

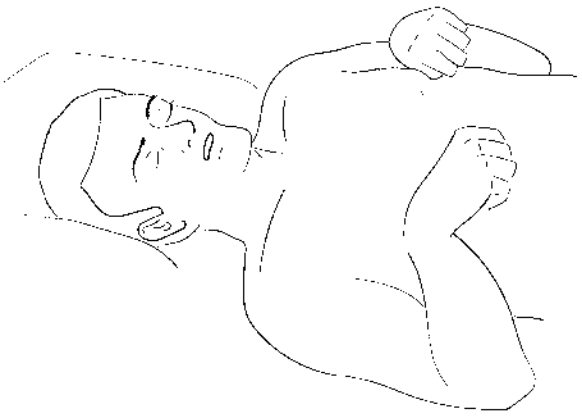


Fig. A2.1 Decorticate rigidity (decorticate posturing)

of the antigravity and paravertebral muscles leading to opisthotonos. Decerebration syndrome is accompanied by a more severe disorder of consciousness caused by a brainstem lesion mainly at the level of the mesencephalon or caudal diencephalon (Fig. A2.2). In cases of unconscious states, we investigate **brainstem reflexes**, which can specify the vertical location of the lesion. These are always examined in the craniocaudal order, the last absent and the first present reflex determine the topical level of the brainstem lesion (Table A2.2).