Rapid response, assessment and management are crucial for neurocritical situations

Acute neurological illness is traumatic for patients and their families. Physicians caring for these patients are often under great distress and need to rapidly assess the situation to allow appropriate stabilization and management.

Emergency Management in Neurocritical Care gives you the tools you need to perform under pressure in the neurocritical or emergency care unit. The no-nonsense approach corresponds to the attitude needed in both acute emergencies and in the neurocritical care unit. Packed with handy tips to improve your care of patients, and written by internationally renowned experts, the book covers:

- Acute Management of Neurological Emergencies
- Cerebrovascular Critical Care
- Infections of the Nervous System
- Neuromuscular Complications Encountered in the Intensive Care Unit
- Neurological Complications and Consultations in General Intensive Care Units
- Acute Neuroimaging and Neumonitoring in Neurocritical Care

Clinical in approach, practical in execution, Emergency Management in Neurocritical Care will help you perform better in pressure situations.
Emergency Management in Neurocritical Care

EDITED BY

EDWARD M. MANNO
MD, FCCM, FAAN, FAHA
Head, Neurological Intensive Care Unit
Cleveland Clinic
Cleveland, OH, USA
Contents

List of Contributors vi
Series Foreword viii
Preface ix

PART I: ACUTE MANAGEMENT OF NEUROLOGICAL EMERGENCIES

1 Hypertensive Emergency 3
Laurie McWilliams

2 Airway Management in the Neurological and Neurosurgical Patient 12
Michael J. Souter

3 Traumatic Brain Injury and Intracranial Hypertension 21
Iain J. McCullagh and Peter J.D. Andrews

4 Critical Care Management of Acute Spinal Cord Injury 32
Edward M. Manno

5 Subarachnoid Hemorrhage 37
Muhammad A. Taqi and Michel T. Torbey

6 Acute Management of Cerebral Ischemia 45
Leonid Groysman and Gene Sung

7 Neurocritical Care of Intracerebral Hemorrhage 55
James M. Gebel Jr

8 Acute Management of Status Epilepticus 63
Jan Claassen

PART II: CEREBROVASCULAR CRITICAL CARE

9 Post-procedural Management of Patients with Aneurysmal Subarachnoid Hemorrhage 73
Tomoko Rie Sampson and Michael N. Diringer

10 Care of the Neurointerventional Patient in the Neurointensive Care Unit 84
Rishi Gupta
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>New Treatment Strategies in the Management of Large Hemispheric Strokes and Intracerebral Hemorrhages</td>
<td>92</td>
</tr>
<tr>
<td>Edward M. Manno</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Presentation and Management of Acute Cerebral Venous Thrombosis</td>
<td>99</td>
</tr>
<tr>
<td>Patricia Canhão and José M. Ferro</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PART III: INFECTIONS OF THE NERVOUS SYSTEM</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Infections in the Neurocritical Care Unit</td>
<td>111</td>
</tr>
<tr>
<td>Denise H. Rhoney, Karen J. McAllen, and Dennis Parker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Diagnosis and Management of Bacterial and Viral Meningitis</td>
<td>123</td>
</tr>
<tr>
<td>Maxwell S. Damian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Encephalitis: Presentation and Management</td>
<td>132</td>
</tr>
<tr>
<td>Ali E. Elsayed and Barnett R. Nathan</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PART IV: NEUROMUSCULAR COMPLICATIONS ENCOUNTERED IN THE INTENSIVE CARE UNIT</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Practical Management of Guillain–Barré Syndrome and Myasthenic Crisis</td>
<td>143</td>
</tr>
<tr>
<td>Alejandro A. Rabinstein</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PART V: NEUROLOGICAL COMPLICATIONS AND CONSULTATIONS IN GENERAL INTENSIVE CARE UNITS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Metabolic Encephalopathies</td>
<td>155</td>
</tr>
<tr>
<td>Edward M. Manno</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Delirium and Sedation in the ICU</td>
<td>162</td>
</tr>
<tr>
<td>Jennifer A. Frontera</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Neurologic Complications of Cardiac Surgery</td>
<td>174</td>
</tr>
<tr>
<td>Cathy Sila</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Neurological Complications of Medical Illness: Critical Illness Neuropathy and Myopathy</td>
<td>182</td>
</tr>
<tr>
<td>Edward M. Manno</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Hypothermia: Application and Use in Neurocritical Care</td>
<td>188</td>
</tr>
<tr>
<td>Edward M. Manno</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Etiologies of Posterior Reversible Encephalopathy Syndrome and Forms of Osmotic Demyelination Syndrome</td>
<td>197</td>
</tr>
<tr>
<td>J. Javier Provencio</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PART VI: ACUTE NEUROIMAGING AND NEUROMONITORING IN NEUROCRITICAL CARE

23 Application of MR Diffusion, CT Angiography and Perfusion Imaging in Stroke Neurocritical Care

Carlos Leiva-Salinas, Wade Smith and Max Wintermark

24 Advanced Monitoring of Brain Oxygenation and Metabolism

Bharath R. Naravetla and J. Claude Hemphill III

Index

The color plate can be found facing page 54.
Contributors

Peter J.D. Andrews, MD, MB, ChB, FRCA
Centre for Clinical Brain Sciences
University of Edinburgh
Edinburgh, UK

Patrícia Canhão, MD, PhD
Department of Neurosciences
Serviço de Neurologia
Hospital de Santa Maria
University of Lisbon
Lisboa, Portugal

Jan Claassen MD, PhD
Division of Neurocritical Care and the Comprehensive Epilepsy Center
Department of Neurology
Columbia University
New York, NY, USA

Maxwell S. Damian, MD, PhD
Department of Neurology and the Neurocritical Care Unit
Cambridge University Hospitals
Cambridge, UK

Michael N. Diringer, MD
Neurology/Neurosurgery Intensive Care Unit
Department of Neurology and Neurological Surgery
Washington University School of Medicine
Saint Louis, MO, USA

Ali E. Elsayed, MD
Mountainside Hospital
Montclair, NJ, USA

José M. Ferro, MD, PhD
Department of Neurosciences
Serviço de Neurologia
Hospital de Santa Maria
University of Lisbon
Lisboa, Portugal

Jennifer A. Frontera, MD
Neuroscience Intensive Care Unit
Departments of Neurosurgery and Neurology
Mount Sinai School of Medicine
New York, NY, USA

James M. Gebel, Jr, MD, MS, FAHA
Cerebrovascular Center
Cleveland Clinic
Cleveland, OH, USA

Leonid Groysman, MD
Neurocritical Care and Stroke Division
University of Southern California
Los Angeles, CA, USA

Rishi Gupta, MD
Department of Neurology, Neurosurgery and Radiology
Emory University School of Medicine
Marcus Stroke and Neuroscience Center
Grady Memorial Hospital
Atlanta, GA, USA

J. Claude Hemphill III, MD, MAS
Department of Neurology
University of California
San Francisco, CA, USA

Carlos Leiva-Salinas, MD
Department of Radiology
Neuroradiology Division
University of Virginia
Charlottesville, VA, USA

Karen J. McAllen, Pharm.D
Department of Pharmacy Services
Spectrum Health Hospitals
Grand Rapids, MI, USA

Iain J. McCullagh, MBChB, FRCA
Department of Anaesthesia, Critical Care and Pain Management
University of Edinburgh
Edinburgh, UK
Series Foreword

The genesis for this book series started with the proposition that, increasingly, physicians want direct, useful information to help them in clinical care. Textbooks, while comprehensive, are useful primarily as detailed reference works but pose challenges for uses at the point of care. By contrast, more outline-type references often leave out the “hows and whys” – pathophysiology, pharmacology – that form the basis of management decisions. Our goal for this series is to present books, covering most areas of neurology, that provide enough background information to allow the reader to feel comfortable, but not so much as to be overwhelming; and to associate that with practical advice from experts about care, combining the growing evidence base with best practices.

Our series will encompass various aspects of neurology, with topics and the specific content chosen to be accessible and useful.

Chapters cover critical information that will inform the reader of the disease processes and mechanisms as a prelude to treatment planning. Algorithms and guidelines are presented, when appropriate. “Tips & Tricks” boxes provide expert suggestions, while other boxes present cautions and warnings to avoid pitfalls. Finally, we provide “Science Revisited” sections that review the most important and relevant science background material, and “Bibliography” sections that guide the reader to additional material.

We welcome feedback. As additional volumes are added to the series, we hope to refine the content and format so that our readers will be best served.

Our thanks, appreciation, and respect go out to our editors and their contributors, who conceived and refined the content for each volume, assuring a high-quality, practical approach to neurological conditions and their treatment.

Our thanks also go to our mentors and students (past, present, and future), who have challenged and delighted us; to our book editors and their contributors, who were willing to take on additional work for an educational goal; and to our publisher, Martin Sugden, for his ideas and support for wonderful discussions and commiseration over baseball and soccer teams that might not quite have lived up to expectations. We would like to dedicate the series to Marsha, Jake and Dan; and to Janet, Laura and David. And also to Steven R. Schwid, MD, our friend and colleague, whose ideas helped to shape this project and whose humor brightened our lives, but he could not complete this goal with us.

Robert A. Gross
Jonathan W. Mink
Rochester, July 2011
Since its beginning in the early 1980s the field of neurocritical care has expanded at a dramatic rate. In the last decade there has been the development of an international society with over 1000 members, a specialized journal with a growing impact factor, accredited fellowship programs, and a board certification process through the United Council of Neurological Subspecialties. To date there are close to 100 neurocritical care units in the United States, a similar number in Europe, and a growing presence in South America and Asia. The inclusion of a textbook of Neurocritical Care in the Neurology in Practice series is a testimony to the field’s growing influence.

The rapid growth of neurocritical care has encouraged a commensurate growth of literature in the field. Interestingly, this has mostly taken the form of single author texts or handbooks primarily designed to disseminate information quickly and systematically to keep pace with this growing field.

This book, *Emergency Management in Neurocritical Care* is the first multi-authored textbook in the field since the first text, *Neurological and Neurosurgical Intensive Care*, was edited by Allan Ropper and Sean Kennedy in 1983. The primary aim is to provide a comprehensive guide to the management of acutely ill neurological or neurosurgical patients wherever they may be located in the hospital. The scope of the book will include basic principles in emergency neurology and critical care, which will review the underlying basic science and cerebrovascular physiology of the critically ill neurological patient. Later sections will focus more on the critical aspects of the neurologically ill. Specific sections dedicated to cerebrovascular disease, neuromuscular disorders, epilepsy, and neurological consultations in general intensive care unit are included. A final section on neuroimaging and neuromonitoring reflects the growing reliance on technology in neurological critical care.

The chapters are written by experts in their respective areas and represent a worldwide distribution of multidisciplinary authors. The book contains more detailed information than a handbook, but is presented in a concise and user-friendly manner to serve as a quick reference when needed. The “Tips & Tricks” and “Science Revisited” sections are designed to increase the readability of the chapters.

Endeavors of this size are not undertaken without help, and I would like to thank Jonathan Mink MD, one of the series editor, for including this topic. I would also like to thank Lewis O’Sullivan, Martin Sugden, Michael Bevan, and Lucinda Yeates at Wiley–Blackwell Publishing who were instrumental in guiding me through this process.

Finally, my father passed away during the editing of this text, and on retrieving his personal items I discovered a number of medals of valor he received during World War II. He never spoke of these and my family was unaware of his possessions. This book is dedicated to him and to all the physicians, nurses, and personnel in the neurological intensive care unit and elsewhere who perform daily acts of valor with no expectation of recognition.

Edward M. Manno

*Cleveland*
Part I

Acute Management of Neurological Emergencies
Hypertensive Emergency
Laurie McWilliams

Neurocritical Care Unit, Cerebrovascular Center, Department of Neurology and Neurosurgery, Cleveland Clinic, Cleveland, OH, USA

Introduction
Hypertension and neurologic disease coexist frequently, either as a cause or consequence of the underlying neurologic disease. In addition, the management of elevated blood pressures in this setting has significant impact on outcomes. Hypertension is defined as systolic blood pressure greater than 140 mmHg or diastolic blood pressure greater than 90 mmHg. The National Health and Nutrition Survey (NHANES) is conducted by the Centers for Disease Control and Prevention obtaining data from US household individuals regarding health and nutrition for the purpose of improving the US health through policy. The NHANES 2005 to 2006 data reported that 29% of the United States population 18 years and older are diagnosed with hypertension. Of the population with treated hypertension, greater than 64% has controlled hypertension. Men have a higher rate of hypertension until the age of 45 when the incidence of hypertension equals between men and women.

In 2006 the mortality from hypertension was reported in 56,561 individuals. Both the prevalence from hypertension and mortality has increased from the late 1990s to the 2000s. The estimated direct and indirect cost of hypertension for the year 2010 was 76.6 billion US dollars.

The sequelae of hypertension include strokes, myocardial ischemia, aortic dissection, and renal insufficiency. The remaining text of the chapter will focus on the management of blood pressure in the specified acute neurologic diseases.

Hypertensive crisis is defined as an abrupt elevation of blood pressure, to a point that the blood vessels are unable to maintain constant blood flow in the setting of increasing perfusion pressures to specific organs, also known as disruption of autoregulation. The end result leads to end-organ damage from ischemia or hemorrhage. The end result leads to end-organ damage from ischemia or hemorrhage.

Patients with blood pressure elevations greater than 180/110 mmHg are categorized into the following diagnoses:

1. Severe hypertension: no to mild symptoms and no acute end-organ damage
2. Hypertensive urgency: significant symptoms and mild acute end-organ damage. Mild end-organ damage is defined as dyspnea and headaches.
3. Hypertensive emergency: severe symptoms with life-threatening end-organ damage.

Life-threatening end-organ damage is defined as acute ischemic stroke, intracerebral hemorrhage, subarachnoid hemorrhage, acute aortic dissection, myocardial infarction, acute heart failure, eclampsia, renal insufficiency, and acute
pulmonary edema, to name a few. The first instinct when dealt with this situation as a practitioner is to acutely correct the problem. However, there are some considerations prior to acutely correcting the blood pressure in a hypertensive crisis. The remainder of the chapter will discuss these considerations in relation to neurologic emergencies.

Hypertensive urgencies include 25% of ED medical visits, while hypertensive emergencies are one-third of the cases. CNS complications are the most frequent of the hypertensive emergencies. The hypertensive emergent patient with neurologic sequelae needs urgent attention, with hourly blood pressure monitoring and neurologic examination in an intensive care unit. Prior to discussing blood pressure management, a discussion of cerebral autoregulation and the parental antihypertensive agents will be reviewed.

**Cerebral Autoregulation**

Cerebral blood flow (CBF) is tightly controlled under the normal conditions, with cerebral perfusion pressures (CPP) ranging from 50 to 150 mmHg. Cerebral perfusion pressures can be calculated from mean arterial pressure (MAP) minus jugular vein pressure (JVP). Intracranial pressure (ICP) is substituted for JVP under conditions where the ICP is greater than the JVP. Cerebral autoregulation involves arteriole caliber changes in response to changes in the blood pressure; however, there are upper and lower limits that lead to a disruption of this system with resultant ischemia or cerebral edema (Figure 1.1).

The underlying mechanisms of autoregulation that allow for vessel caliber changes are myogenic and metabolic. When the MAP decreases, the arterioles constrict to increase the CBF; however, if hypotension persists beyond the lower limit threshold, resultant cerebral ischemia exists. If the blood pressure continues to increase above the higher limit threshold, the result is hyperemia and cerebral edema. However, in brain dysfunction, the blood–brain barrier and cerebral endothelium is disrupted, leading to leaky blood vessels with subsequent fibrinoid deposition into the cerebral vasculature. This results in vascular narrowing, with compensatory vasodilation. In these circumstances the autoregulation curve follows a more linear pattern with the CBF being dependent on perfusion pressures.

Normal CBF is 50 mL/100 g brain tissue per minute. Reversible injury, occurs at 15–20 mL/100 g/min, and irreversible injury is less than 15 mL/100 g/min. The occurrence of cell death is based on the product of the degree and length of time of ischemia. The ischemic penumbra is vulnerable tissue with impaired autoregulation and low blood flow despite high oxygen extraction. Therefore the tissue is salvageable but has a high risk of becoming ischemic if the blood flow is not recovered in a short period of time.

![Autoregulation graph](image)

**Figure 1.1.** Autoregulation maintains cerebral blood flow relatively constant between 50 and 150 mmHg mean arterial pressure. The range is right shifted in chronically hypertensive patients. (Reproduced from Ruland and Aiyagari. *Hypertension* 2007; 49: 978, with permission from Wolters Kluwer Health.)
An EEG is a useful tool for monitoring seizures, but also for detecting cerebral blood flow. In the operation room, older studies have shown that EEG can detect real-time ischemia. When cerebral blood flow reaches 25–30 mL/100 g/min, an EEG demonstrates a change in morphology, amplitude, and frequency. When the CBF decreases to less than 15 mL/100 g/min, the EEG becomes isoelectric. The neurons that produce the excitatory post-synaptic potential (EPSP) and inhibitory post-synaptic potential (IPSP) for the electrodes are the same neurons (pyramidal neurons) that are sensitive to hypoxia.

Antihypertensive Agents
Hypertensive emergency can be fatal, and needs prompt treatment. The initial treatment is blood pressure control, in a reliable and controlled fashion, therefore oftentimes, requiring parental agents and arterial blood pressure monitoring. There are multiple classes of antihypertensives one has to choose from; however, there are also many factors to consider prior to administration. The most important factor to consider in neurologic damage is increased intracranial pressure. A few class of antihypertensive agents work via vasodilatory mechanisms, which can lead to further increases in intracranial pressure and potentially further worsening of neurologic injury. Another factor is the onset and duration of action. Rapid fluctuations of hypotension and hypertension can lead to worsening cerebral injury. An agent that can be turned off and out of the system quickly is more desirable in case of an acute hypertensive episode.

Preferred Agents for Hypertensive Emergencies with Brain Dysfunction
Beta Blockers
Labetalol is a selective alpha-1 and nonselective beta antagonist. The onset of action is 2–5 minutes with a peak effect seen in 5–15 minutes. The hypertensive effect can last for 2–4 hours. Beta action does cause a decrease in heart rate but maintains the cardiac output. Similarly, cerebral perfusion is maintained with the use of beta blockers.

Start with a loading dose of 20 mg, increasing subsequent doses from 20 to 80 mg every 10 minutes to the desired effect. In the author’s institution, if repeat labetalol boluses do not result in the desired effect, an infusion is initiated starting at 1–2 mg/min.

Esmolol is a short-acting beta antagonist, with no direct affect on the peripheral vasculature. Decreased blood pressure is secondary by decreasing cardiac output. The onset of action is 60 seconds, with a duration of action of 10–20 minutes. Esmolol has a unique metabolic profile, being metabolized by red blood cell (RBC) esterases. In the setting of anemia, Esmolol can have a prolonged effect. Due to its pure beta action, caution should be used in patients with COPD. Similarly it should be avoided in patients in decompensated heart failure, due to compromising myocardial function.

Start with a loading dose of 500–1000 μg/kg, with a continuous infusion at 50 μg/kg/min to a maximum of 300 μg/kg/min.

Calcium Channel Blockers
Three types of calcium channel blocker exist: dihydropyridines, phenylalkylamines, and benzothiapines. The two types of calcium channels that exist in the vasculature are L-type and T-type.
The action of calcium channel blockers on L-type channels decrease calcium influx, resulting in elevated GMP levels. The elevated GMP levels lead to vascular smooth muscle relaxation, vasodilation and decrease systolic blood pressure.

Nicardipine and clevidipine are the preferred parental calcium blocker agents for cerebrovascular hypertensive emergencies. Nicardipine crosses the blood brain barrier, leading to vasodilation of the small-resistance arterioles, with little to no increases in intracranial pressure. The infusion rate starts at 5 mg/h, with incremental increases 2.5 mg/h every 5 minutes for a maximum infusion 30 mg/h. The onset of action is 5–15 minutes, with duration of action 4 to 6 hours.

Of note, nicardipine has other properties that make it attractive in neurological diseases. It has a high affinity to ischemic cerebral tissue due to the acidic pH of ischemic tissue. Once in the cell, it is transformed to its active form, which may lead to a direct neuroprotective effect.

The effect of nicardipine on intracranial pressure has been studied. Narotam et al. (2008) performed a prospective case-control study of 30 patients with hypertensive emergencies in acute brain disease. Nicardipine was the first-line antihypertensive agent. The results supported the ability to maintain cerebral perfusion pressures above 70 with no increase in ICP and increased parenchymal brain tissue oxygenation.

Clevidipine is a third-generation dihydropyridine calcium channel blocker, recently used in a trial of blood pressure management in acute intracerebral hemorrhage. The drug acts by arteriole dilation, with an onset of action 2–4 minutes and a duration of action 5–15 minutes. It is metabolized by red blood cell esterases. Clevidipine has antioxidative properties as a free-radical scavenger. Continuous infusions start at 1–2 mg/h, and is increased every 90 seconds until blood pressure goals are attained. However, there are a few less attractive features of the drug: 1) infused in a lipid emulsion, requiring triglyceride monitoring during infusion, 2) contraindicated in patients with allergies to soy and egg products, and patients with lipid metabolism disorders, and 3) can develop microbial growth in solution.

### Other Agents Used for Hypertensive Emergencies

#### Nitric Oxide Vasodilators

Sodium nitroprusside is a potent arterial and venous vasodilator, leading to significant preload and afterload reductions. However, ICP elevations can occur in patients with neurologic injury. The first studies were performed on neurosurgical patients under anesthesia revealing vasodilation of large-capacitance vessels leading to vasodilation and increased intracranial pressure. Another negative consequence is cyanide toxicity. Sodium nitroprusside contains 44% of cyanide, which is further metabolized to thiocyanate by the liver, and eliminated by the kidneys. There is an increased risk for cyanide toxicity in patients with liver and kidney dysfunction. Cyanide toxicity leads to cellular hypoxia with neurologic consequences and cardiac arrest. The neurologic consequences include encephalopathy, seizures, and coma. Thus, the use of sodium nitroprusside and other nitric oxide drugs are discouraged due to the potential for worsening intracranial pressures.

Diuretics have no role in the acute management of hypertensive emergencies in neurological and nonneurological disorders due to the increased frequency of volume depletion. Specifically in the neurological patient, altered mental status and dysphagia can further exacerbate volume depletion, leading to increased fluid administration in the acute setting to prevent further dehydration and kidney injury.

A list of medications used to treat acute hypertensive emergencies and the doses used are listed in Table 1.1.

### Acute Ischemic Stroke

Blood pressure management in acute ischemic stroke is complex; lowering blood pressure could potentially worsen the infarct size and cause neurologic deterioration, while allowing blood pressures to remain elevated could lead to hemorrhagic transformation and worsening brain edema. If the patient is a thrombolytic candidate or received thrombolytics, pressures excessively elevated can also lead to hemorrhagic transformation. Retrospective analysis of outcomes post-thrombolysis has also shown a worse outcome in
Table 1.1. Antihypertensives and management of neurologic emergencies

<table>
<thead>
<tr>
<th>Drug</th>
<th>Mechanism of action</th>
<th>Dosage</th>
<th>Onset</th>
<th>Duration</th>
<th>Contraindications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labetalol</td>
<td>$\alpha_1\beta$ antagonist</td>
<td>Loading doses 20 mg with repeated boluses every 10 min, infusion rates 1–2 mg/min for target blood pressure</td>
<td>2–5 min</td>
<td>2–4 h</td>
<td>Reactive airway disease, COPD, Decompensated heart failure, Bradycardia, Second or third degree heart block</td>
</tr>
<tr>
<td>Esmolol</td>
<td>$\beta_1$ antagonist</td>
<td>Loading dose 0.5–1.0 mg/kg, infusion rates 50 μg/kg/min to max 300 μg/kg/min</td>
<td>60 s</td>
<td>10–20 min</td>
<td>Reactive airway disease, COPD, Decompensated heart failure, Bradycardia, Second or third degree heart block</td>
</tr>
<tr>
<td>Nicardipine</td>
<td>Dihydropyridine calcium channel antagonist</td>
<td>Initial infusion 5 mg/h, increasing 2.5 mg/h every 5 min, maximum 15 mg/h</td>
<td>5–15 min</td>
<td>4–6 h</td>
<td>Severe aortic stenosis</td>
</tr>
<tr>
<td>Clevidipine</td>
<td>Dihydropyridine calcium channel antagonist</td>
<td>Initial infusion 1–2 mg/h, increasing the dose x2 every 90 s to max 32 mg/h</td>
<td>6 min</td>
<td></td>
<td>Defective lipid metabolism disorders</td>
</tr>
<tr>
<td>Enalaprilat</td>
<td>ACE inhibitor</td>
<td>Initial dose of 0.625 with repeated doses 1.25 mg every 6 h</td>
<td>15 min</td>
<td>12–24 h</td>
<td>Acute renal failure, Acute MI, Bilateral renal artery stenosis, Pregnancy hyperkalemia</td>
</tr>
<tr>
<td>Sodium nitroprusside</td>
<td>Nitric oxide donor leading to vascular smooth muscle relaxation via intracellular second messenger systems</td>
<td>Initial dose of 0.3–0.5 μg/kg/min, increasing 0.5 μg/kg/min for desired effect, max dose 2 μg/kg/min.</td>
<td>1–3 min</td>
<td>1–3 min</td>
<td>Increased intracranial pressures, Acute MI, Hepatic or renal failure due to increase risk for cyanide toxicity</td>
</tr>
</tbody>
</table>
patients with a history of hypertension, despite the administration of thrombolysis. Studies focusing on blood pressure management in acute ischemic stroke have shown that patients with lower blood pressure on admission had poor outcomes. Vemmos and colleagues examined the mortality at 1 month and 12 months after ischemic and hemorrhagic strokes in relation to admission blood pressures. Their findings concluded that patients with ischemic strokes had the best outcomes with an admission systolic blood pressure of 120–140 mmHg, and patients with an admission systolic blood pressure less than 101 mmHg or greater than 220 mmHg had the highest mortality rates. Therefore, current guidelines recommend maintaining systolic blood pressure less than 220 mmHg and diastolic blood pressure less than 120 mmHg. The majority of patients will reset to normotensive days after their stroke.

In regards to blood pressure augmentation during an acute stroke, there are no good studies to date to support artificially raising blood pressures in an acute stroke. Current recommendations are to discontinue home blood pressure medications and allow the blood pressures to rise to their specific targets irrespective of thrombolysis. If thrombolytics have been instituted, patients need monitoring in an intensive care unit, preferably a neurocritical care unit, with the use of short-acting parental antihypertensives if patients’ blood pressures are raised outside their specific targets.

**Intracerebral Hmorrhage**

Intracerebral hemorrhages represent 15% of all strokes. Despite more sophisticated medical interventions, neurological outcome and mortality continue to significantly impact patients with intracerebral hemorrhages. More specifically, patients with a decrease in the neurologic examination prior to hospital admission have a significantly greater mortality. The initial neurologic deterioration is frequently due to rebleeding of the initial hemorrhage.

There has been poor evidence for guiding blood pressure goals in intracerebral hemorrhages; however, the 2010 Stroke Guidelines have a new recommendation based on two clinical trials: INTERACT and ATACH. The new guidelines state that it is “probably safe” to lower systolic blood pressures less than 140 mmHg if presenting systolic blood pressures are less than 220 mmHg. However, there is insufficient data for a defined blood pressure target.

Kazui et al. (1997) examined the risk factors for hematoma enlargement. 83% of the subjects had a pre-existing diagnosis of hypertension and 76% of the hemorrhages were in classical, hypertensive locations. In their study population, Kazui et al. (1997) noted that admission systolic blood pressure greater than 200 mmHg was significantly associated with hematoma enlargement.

The INTERACT trial randomized 404 patients to intensive blood pressure control of systolic blood pressure less than 140 mmHg or guideline-based blood pressure control of systolic blood pressure less than 180 mmHg for the first 24 hours to 7 days after stroke onset. 296 patients had all CT scans available for full statistical analysis. Patients in the intensive blood pressure lowering group showed reduced hematoma volumes, 3.15 cc and 2.45 cc at 24 and 72 hours, respectively. However, the results have been questioned due to enrollment bias with patients with smaller hemorrhage volumes than previous trials, less acuity based on NIHSS and GCS: NIHSS ranged from 5 to 15 and GCS ranged 13 to 15. The patient population was more diverse due to hospitals located in Australia, China, and South Korea, with possible different etiologies and pathophysiologies involved.

The ATACH trial enrolled 60 patients to one of three tiers of blood pressure goals within 6 hours of symptom onset. The primary outcomes included neurologic deterioration and serious adverse events. They did not analyze hematoma growth or perihematoma edema. The most serious adverse events and neurologic deterioration occurred in the most intensive tier, systolic blood pressure less than 140 mmHg. There was no difference in mortality between the groups. The ATACH trial produced opposite results to the INTERACT trial, showing more negative outcomes in patients with systolic blood pressures less than 140 mmHg after stroke onset. However, as pointed out, ATACH did not analyze the hematoma volumes and both studies had different patient populations.

There is still no correct answer for the low end of systolic blood pressure in intracerebral
hemorrhage, or if patients have a worse outcome with high or low blood pressure. We still need high-powered studies to assist with this fundamental management of intracerebral hemorrhage in the acute setting.

**TIPS & TRICKS**

Elevated blood pressures in intracerebral hemorrhage are frequently seen. However, persistent elevated blood pressures hours after the initial insult can be an indicator of rebleeding or worsening edema. If blood pressures are not responding to antihypertensives, a dose of mannitol or hypertonic saline can be given with close blood pressure monitoring. If blood pressures decrease, the persistent hypertension is an indicator of a worsening edema.

**Blood Pressure and Aneurysmal SAH**

Subarachnoid hemorrhage is a devastating disease, with a high mortality depending on the severity of the hemorrhage. The risk factors for aneurysmal subarachnoid hemorrhage include hypertension, alcohol use, and tobacco use, Adult Polycystic Kidney Disease, and connective tissue disorders. 30-day mortality from subarachnoid hemorrhage has been reported as high as 50% in the AHA guidelines, with the amount of blood, medical comorbidities, and time to treatment being important factors affecting the outcome. However, the goal of this chapter is to discuss blood pressure management in subarachnoid hemorrhage. Blood pressure goals depend on the state of the aneurysm – unsecured or secured.

Many factors are thought to contribute to the risk of rebleeding in the unsecured aneurysm and the literature is currently unsure of the role of blood pressure and rebleeding risk. However, most centers in America will maintain a systolic blood pressure of less than 160 mmHg. The current stroke guidelines do not give an absolute value for blood pressure control; however, they recommend that the blood pressure should be controlled. For blood pressure management, the use of short-acting parental antihypertensive agents should be instituted.

After securing the aneurysm, the goal of blood pressure focuses on vasospasm management. Vasospasm is the arterial narrowing secondary to inflammatory changes from blood products from the initial subarachnoid hemorrhage. Vasospasm can lead to neurologic deficits by reduced blood flow and ischemic brain tissue, collectively termed “delayed cerebral ischemia.” Nimodipine, a calcium channel blocker, is the only proven drug that improves the outcomes in patients with cerebral vasospasm in the context of subarachnoid hemorrhage. Detecting cerebral vasospasm will be discussed in another chapter of this textbook, and the hypertensive management of vasospasm will be discussed only briefly here.

The goal of management of vasospasm is optimizing oxygenation to the brain. During the management of vasospasm, patients require intensive care monitoring for arterial catheterization and triple lumen catheters. This is performed by reducing cerebral metabolism and intracerebral pressures, and optimizing cerebral perfusion. Blood pressure management is paramount in optimizing cerebral perfusion pressures, which is achieved through the use of hemodynamic augmentation. Considerable controversy exists as to the best method to achieve increased cerebral blood flow in the patient with severe vasospasm. However, it is known that during the acute period of vasospasm cerebral autoregulation is disturbed. Methods to induce hypertension or increased cardiac output have been advocated and may require additional intravascular monitoring. When these measures have not resulted in reversal of delayed cerebral ischemia, patients are referred for intra-arterial opening of the vessels.

**Dysautonomia in Guillain–Barre Syndrome (GBS)**

Dysautonomia is now one of the leading causes of increased mortality in GBS. It is a very common phenomenon in GBS, with increased risk when patients present with respiratory failure, tetraplegia, or bulbar involvement. It is defined as overactivity or underactivity of the sympathetic
system, causing either extreme hypertension and tachycardia and/or extreme hypotension and bradycardia.

Cortelli et al. (1990) have found pathological lesions in the intermediolateral horns of the spinal cord, sympathetic chains of white rami, and involvement of glossopharyngeal and vagus nerves in patients with dysautonomia from GBS. Durocher et al. (1980) examined the catecholamine levels of patients with dysautonomia, resulting in the high urinary catecholamine secretion of VMA, HVA, and 5-HIA; high CSF dopamine and serotonin levels; and normal serum serotonin levels.

These studies provide evidence for the underlying sympathetic pathology presenting with the signs of dysautonomia; however, the literature is scarce in the management of dysautonomia. Due to concerns for hypotension, it has been recommended to allow patients to maintain elevated blood pressures unless end-organ failure proceeds. When patients do progress to hypotension, pressors are indicated, and with severe bradycardia, transcutaneous pacing may be indicated.

**Hypertensive Encephalopathy**

Hypertensive encephalopathy is an entity seen in patients with acute blood pressure elevations in the setting of many clinical scenarios. A later chapter will be dedicated to hypertensive encephalopathy, however, to initiate the discussion on blood pressure management, it should be understood that the parietal-occipital lobes are preferably involved due to the lack of sympathetic innervation in the posterior circulation. Acute blood pressure elevations lead to hyperperfusion and blood–brain barrier dysfunction, with protein and fluid extravasation leading to vasogenic edema and, sometimes, intracerebral hemorrhage.

The clinical effects of hypertensive encephalopathy include, but are not limited to, headache, altered mental status, visual changes, seizures, and coma.

Blood pressure management needs careful attention, with acute lowering of the MAP by 25% of admission MAP or diastolic less than 100 mmHg within 1 hour, to prevent seizures and intracranial hemorrhage. Short-acting agents are a better choice for tighter blood pressure control.

**Bibliography**


Talbert RL. The challenge of blood pressure management in neurologic emergencies. *Pharmcotherapy* 2006; 26: 123S–130S.

Airway Management in the Neurological and Neurosurgical Patient

Michael J. Souter

Department of Anesthesiology & Pain Medicine, and Department of Neurological Surgery, University of Washington, Department of Anesthesiology, Harborview Medical Center, Seattle, WA, USA

Introduction

The term “airway” is an oversimplification of an anatomical canal that serves many functions. This anatomical and functional distribution of the oropharynx, nasopharynx, and larynx allow for communication, mastication, swallowing, and continuous respiration.

A set of complex interconnections and reflex arcs, located diffusely throughout the brain, control the musculature of the pharynx and larynx. The diffuse distribution of these control centers and the complexity of the integration needed to coordinate these centers provide insight into the ease with which the airway can be compromised.

A masticatory center is located in the dorsolateral and anterolateral frontal cortex. Reflex swallowing is mediated by the lateral precentral gyri, postcentral gyri, supplementary motor area, insular cortex, and basal ganglia. These areas modulate the activity of the cranial nerve nuclei in the pons and brainstem. The control of respiration itself is dynamically affected by mechanical receptors in the upper airways, as well as neurohumoral and chemoreceptor activation.

Airway difficulties are often encountered after traumatic brain injury with over 50–70% of head injuries experiencing associated facial injury. Airway compromise can arise from associated soft tissue swelling (often with frightening speed of onset), hemorrhage and secretions, and fractured teeth. Maxillary fractures are associated with facial edema and pharyngeal blood, but may also disrupt the skeletal support of the oropharyngeal musculature leading to reduced pharyngeal dimensions, and increased susceptibility to obstruction.

Focal neurological insults to the midbrain, cerebellum, or brain stem (injury, stroke, demyelination) can adversely affect airway control centers. More diffuse disease (injury, infection, inflammation, ischemia) can threaten consciousness with the consequent impairment of cough and swallow.

A decreased level of consciousness can lead to a reduction in airway muscle tone which may lead to airway obstruction. Obstruction of the airway results in hypoxia, hypercarbia, and
further diminishes airway control. Subsequent increase in respiratory effort will generate negative intrathoracic pressure and further collapse airways.

**CAUTION**

Care must be taken when attempting to alleviate an obstructed airway. Intervention itself can create the possibility of iatrogenic injury to the airway. Lip laceration, bleeding, dental damage, and tongue edema can all result from the use of poor technique in airway instrumentation, while repeated unsuccessful attempts at intubation may induce edema of the pharynx, epiglottis, and cords.

**Assessment**

The urgency of intubation should consider the neurological condition of the patient and the potential effects of hypercarbia and/or hypoxia. Either will lead to cerebral vasodilation with subsequent increases in cerebral blood volume and intracranial pressure.

The need for intubation requires clinical judgment. Some indications for intubation are listed in Table 2.1. They can often coexist to amplify the urgency. Once the decision has been made to intubate the patient, a number of questions will need to be addressed.

- What precautions are required?
- How easy is it to maintain a patent airway?
- How easy is it to intubate the airway?

**Preparation**

In ideal circumstances endotracheal intubation should be a structured and orderly process. This requires a thorough preprocedural preparation that should include optimization of the environment, with suction equipment connected, tested, and immediately at hand. Oxygen, tubing, and an inflatable bag are essential, and a broad range of endotracheal tubes should also be available. A 7 mm tube will fit most adults and induce minimal flow restrictions. Larger tubes (8 mm), however, do allow for easier suctioning and/or bronchoscopy if needed.

Removing the gastric content prior to intubation is desirable since most patients will not have been fasting in an emergency situation. Existing gastric tubes should be drained, but insertion at this point is not recommended. The operator should identify and assign assistants to pass equipment, to monitor vital signs and oxygenation, to immobilize the head in case of cervical spine injury (see below), or to apply cricoid pressure. This maneuver presses on the only competent cartilage ring in the trachea to compress and close the esophagus. Its utility is controversial with some arguing that it increases the difficulty of intubation without adding additional protection.

If cricoid pressure is to be utilized, the clinician should carefully inform the assistants (a) on exactly how and when to apply this pressure, and (b) to stop only when instructed. A rapid sequence induction should be the norm in most urgent or emergent cases, with good quality of sedation, facilitated by adequate muscle relaxation.

### Table 2.1. Indications for intubation

<table>
<thead>
<tr>
<th>In the field and in hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Immediate (life-threatening hypoxia likely)</td>
</tr>
<tr>
<td>- persistent airway obstruction despite airway insertion</td>
</tr>
<tr>
<td>- inability to bag-mask ventilate</td>
</tr>
<tr>
<td>- Urgent</td>
</tr>
<tr>
<td>- Glasgow Coma Scale &lt; 8</td>
</tr>
<tr>
<td>- protection of the lower respiratory tract from aspiration</td>
</tr>
<tr>
<td>- anticipated occlusion by:</td>
</tr>
<tr>
<td>- edema (burns, angioedema)</td>
</tr>
<tr>
<td>- hematoma</td>
</tr>
<tr>
<td>- displacement of a laryngotracheal fracture</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In-hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td>- control of intracranial pressure by controlling ( pCO_2 )</td>
</tr>
<tr>
<td>- therapeutic ventilation for hypoxemia/hypercarbia in:</td>
</tr>
<tr>
<td>- pulmonary contusion/edema/infection</td>
</tr>
<tr>
<td>- flail chest</td>
</tr>
<tr>
<td>- therapeutic and diagnostic procedures in combative or uncooperative patients</td>
</tr>
<tr>
<td>- high metabolic demand from work of breathing</td>
</tr>
</tbody>
</table>
Induction drugs comprise hypnotics, analgesics, and paralytics. Their use should consider the desired speed of action, hemodynamic consequences, and side effects. For hypnotics, there is little to choose between thiopental (3–5 mg/kg) and propofol (2–3 mg/kg), as both cause similar degree of reduction in cardiac output. Etomidate (0.3 mg/kg) has the least hemodynamic effect while ketamine (1–2 mg/kg) will maintain or even increase blood pressure with attendant tachycardia. There is controversy regarding the effect of etomidate upon adrenal suppression, which tempers its use. Midazolam (0.3–0.4 mg/kg) may be used for induction, causing slight hypotension but less than propofol or thiopental. All agents will produce transient apnea but ketamine has the least effect, followed by etomidate. Fentanyl (1–2 mg/kg) can synergistically reduce hypnotic doses at induction and serves to decrease subsequent coughing, as well as respiration. It has the most favorable hemodynamic profile of the opiates, and is consequently the most useful at induction. Paralytic drugs provide the highest quality relaxation for intubation, but at the risk of significant apnea and hypoxia if the airway can be neither intubated nor ventilated. However, coughing or moving on intubation does have consequences and the risk/benefit must be carefully considered for each patient. The shortest duration of effect is 3–5 minutes for succinyl choline (1–1.5 mg/kg). This well established agent has the fastest overall onset (45 s) but does have limitations due to hyperkalemia seen in burns and the recently immobilized (more than 72 hours since burn/immobility). Vecuronium, rocuronium or cisatracurium are acceptable alternatives, with rocuronium (1 mg/kg) swiftly working at 60 seconds post injection, but the effect lasting longest to 60 minutes. Cisatracurium (0.15 mg/kg) and vecuronium (0.1 mg/kg) take 2–3 minutes respectively to work, but effects last for 30–40 minutes. There is no evidence of any protective effect of any of the above agents upon the brain.

Support of the Airway
Supporting the airway with bag mask ventilation is a greatly undervalued skill which is intrinsic to intubation, and is lifesaving when done correctly. Its application allows for the collection of necessary resources and personnel to safely secure the airway. Competence requires frequent practice. An examination of Figure 2.1(A) illustrates that, in the supine position, there is a tendency for both the mandible and tongue to fall back against the posterior pharyngeal wall obstructing the airway. The application of jaw lift is achieved by applying upward pressure at the angle of the mandible,