

The Experts Consensus for Patient Management of Neurosurgical Critical Care Unit in China (2015)

China Neurosurgical Critical Care Specialist Council (CNCCSC)

Key words: Experts Consensus; Multidisciplinary; Neurosurgical Critical Care; Patient Management; Standardization

INTRODUCTION

Great changes have taken place in modern neurosurgery in the past decades. Contrasting models of management for complex neurosurgical patients have been developed in China as the specialty evolving, thus arise many controversies. Clinical demand calls for an expert consensus on neurosurgical inpatients management, especially for the subspecialty of neurosciences critical care (NCC).

By far, we have witnessed the rapid development of critical care medicine in the past 30 years. With the honorable milestones standing by, NCC is progressively regarded as an important part of neurosurgery. Functioning as a multidisciplinary subspecialty, NCC aims to provide joint effort from multiple disciplines, including Neurosurgery, Critical Care Medicine, Neurology, Emergency Medicine, Laboratory Medicine, Neurosurgical Nursing, etc. The Chinese Neurosurgery Society invited 356 experts in this subspecialty to formulate The Experts Consensus for Critical Care Management of Neurosurgical Patients in China (consensus).

The formation procedures of the consensus have four stages: (1) Statement of the purpose, (2) literature review and retrieval, (3) quality assessment and classification of evidence, as well as levels of recommendation, (4) manuscript review process, during this process we held seven conferences within 2 years in Beijing, Tianjin, Hangzhou, Chengdu, Guangzhou, Hainan, and Qingdao to reach a final agreement of the consensus manuscript. Each term of the consensus was arrived after fair vote to ensure this document represents the consensus. Topics of controversial are excluded from the contents, like hypothermia. This edition will be generalized widely in China and will be up-to-dated every 5 years. The consensus is supported by Chinese Medical Association, Chinese Neurosurgical Society. Standards from the Center for Evidence-Based Medicine at

Oxford University was adopted in grading by recommendation and evidence level [Table 1] with the guidance from Peking University Evidence-based Medicine Center.

DEFINITION AND ADMISSION CRITERIA OF NEUROSURGICAL CRITICAL CARE UNIT

Definition of neurosurgical critical care unit

Neurosurgical critical care unit (NCCU) is a specialized intensive care unit (ICU) that provides personalized multidisciplinary clinical care for critically ill neurological and neurosurgical patients. NCCU utilizes advanced monitoring methods based on latest health care technologies and is staffed by a multidisciplinary teams with qualified mastery of modern medical knowledge and standard procedural skills of neurosurgical patient care.

Admission criteria for neonatal intensive care unit

Patients with acute cerebrovascular diseases with Glasgow Coma Scale (GCS) under 12, traumatic injury of the brain and spinal cord, critically ill neurological and neurosurgical patients in the perioperative period, severe infection of the central nervous system (CNS), patients with continued seizure, and other critically ill neurological and neurosurgical patients.

ESSENTIAL FACILITIES OF NEUROSURGICAL CRITICAL CARE UNIT

The Guideline for the Establishment and Management of ICU in China (2006)^[1] is used as a basic reference to build specialized NCCU. As a multifunction unit, NCCU should be

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equipped with qualified medical and nursing staff, a specially designed ward, and essential monitoring equipment. The medical and nursing staff should pass specialized training in neurology and critical care medicine. The team should be supervised by a senior associate professor or above the level. It is recommended that the physician to patient ratio be around 0.5:1–1:1 and nurses to patient ratio 2:1–3:1. Respiratory therapists, electrophysiology technicians, rehabilitation physical therapists are all indispensable team members.

It is recommended that each NCCU contains 10–20 ICU beds/100 neurosurgery inpatients. Each bed should take an area of 15–18 m², at least 9.5 m². The distance between adjacent beds should be above 1 m. For the single bedrooms, each patient should take a recommended area of 18–25 m². The beds should meet the special requirements of critical care. They should be designed to allow position and posture change of patients. When resource permits, positive and negative pressure rooms should be essentially configurated, and air cleaning facilities should be equipped when necessary. The facility standards of each NCCU should be in accordance with the level of the medical center and specific clinical requirement and resource availability of each individual unit. A recommended set of general and essential facilities include: (1) General facilities: Multi-function monitors, respirator, infusion pump, defibrillator, electrocardiogram (ECG), sputum sucker, enteral nutrition system, intermittent pneumatic compression devices, hypothermia therapeutic facility, blood-gas analyzer, multi-function air cushion bed. Mobile imaging facilities including bedside X-ray, bedside ultrasonography should be available as well as corresponding microbial laboratory tests). (2) Neurosurgery monitoring facilities: Intracranial pressure (ICP) monitor, trans-cranial Doppler (TCD), and electroencephalography (EEG). (3) Optional supporting facilities: Fiber bronchoscopy, mobile computed tomography (CT), brain tissue oxygen monitor, brain tissue micro-dialyzer, and airway humidifier.

STANDARD PROCEDURES FOR MANAGEMENT OF NEUROSURGERY EMERGENCY AND CRITICAL CARE PATIENTS

Managing patients with severe traumatic brain injury, acute cerebrovascular diseases, and severe neurological

emergency complicated with multiple organ dysfunctions is becoming more challenging because of the increasing incidence and complexity of life-threatening conditions. Urgent and effective management is required to save these patients. Therefore, it is crucial to establish a green channel for emergency,^[2] and closely monitor severely ill patients during the preoperative period. A standardized operation procedure for the evaluation and management of severely ill neurosurgical emergency patients is recommended.

GENERAL AND NEUROLOGICAL EVALUATION OF NEUROSURGICAL CRITICAL CARE PATIENTS

Stabilize vital signs and general physical examination

When a patient is admitted to neurosurgical critical care unit, physicians should first stabilize all vital signs and do a thorough physical examination to assess the general condition and severity of patient's illness. This is followed by selected fast evaluation of the circulatory, respiratory, endocrine, hematological, as well as the muscular and skeletal system, etc. Closely monitor ECG, noninvasive blood pressure, continuous invasive blood pressure, central venous pressure (CVP), liver and renal function, serum and urine osmotic pressure, coagulation function, body temperature, peripheral oxygen saturation etc. Guided by real-time monitoring, prompt adjustment to the treatment goal and management plan can be made, to effectively maintain vital signs and alleviate life-threatening conditions.

Neurological examination and monitoring of neurological function

Specific Neurological examination and functional scoring

After being admitted to NCCU, detailed neurological examination should be taken for the patient, including general responsiveness, eye and pupil, cranial nerve function, somatic movement and sensory function, physiological and pathophysiological reflexes, etc. Evaluate GCS of the patient. Thus, a general impression of patient's neurological function is obtained.

Monitoring of intracranial pressure and cerebral perfusion pressure

Intracranial pressure is the pressure applied to the cranial cavity wall by intracranial contents depending on the patient's

Table 1: Evidence-based criterion for consensus of neurosurgical critical care management

Recommended grade	Evidence grade	Treatment/prevention, cause/damage	Prognosis	Diagnosis
A	1	Systemic reviews of randomized control trials, or single randomized control trial, or "all or none" evidence	Systemic review of initial cohort studies, or single initiated cohort study, or "all or none" case series	Systemic reviews of primary diagnostic studies, or single primary diagnostic study
B	2	Systemic review of cohort studies or case control studies, or single cohort study or case control study	Systemic retrospective cohort studies, or single retrospective cohort study	Systemic review of secondary diagnostic studies, or single secondary diagnostic study
C	3	Case series, or expert's reviews	Case series	Diagnostic studies with severe bias

Regarding the evidence grades and recommended grading criteria in this study: (1) It is mainly based on the evidence and recommended grading system proposed by Oxford Centre for Evidence-based Medicine in 2001, with minor modification. The details were listed in the above table. (2) It not only includes grading for treatment/prevention, but also includes cause/damage, prognosis and diagnosis etc. (3) The recommended grading corresponds to evidence grading. A, B and C represent strong recommendation, general recommendation and weak recommendation respectively.

clinical condition and current situation. If necessary, invasive ICP monitoring should be considered in NCCU. Changes in ICP and fluctuations of cerebral perfusion pressure (CPP) require close monitoring in NCCU. Therefore, invasive ICP monitoring can be used for patients with cerebrovascular disease, severe infection, and severe traumatic brain injury, etc. However, there are no standardized indications for performing invasive ICP monitoring. In this consensus, we reached generally recommended indications for ICP monitoring, graded by recommendation and evidence level according to evidence-based medicine criteria: (I) Traumatic brain injury: (1) GCS 3–8, with abnormal head CT scan findings (hematoma, contusion, edema, herniation, or compressed basal cistern), we recommend to monitor ICP (evidence level Grade 2, recommendation level B); (2) GCS 3–8, without abnormal CT findings. If the patient's age is above 40, with systolic blood pressure (SBP) below 90 mmHg, and is highly suspected to have progressive severe neurological conditions. It is accepted to consider ICP monitoring when necessary (evidence level Grade 3, recommendation level C);^[2] (3) GCS 9–12, and if patients have signs of elevated ICP, invasive monitoring can be considered in certain conditions based on a comprehensive evaluation of clinical presentation, imaging findings, comorbid illnesses, and the need for sedation (evidence level Grade 3, recommendation level C).^[3–6] (II) For patients who lost consciousness after hemorrhagic conditions, like subarachnoid hemorrhage, spontaneous intracerebral hemorrhage and intraventricular hemorrhage that requires external ventricular drainage (EVD), ICP monitoring should be considered for specific conditions when necessary (evidence level Grade 3, recommendation level C).^[7] (III) Perioperative brain tumor patients could have ICP monitoring before, during and after operation in necessary conditions (evidence level Grade 3, recommendation level C). (IV) Patients who developed refractory elevated ICP after cryptococcal meningitis, tuberculosis meningitis, and viral encephalitis, should initiate ICP monitoring and undergo EVD to control ICP (evidence level Grade 3, recommendation level C). Currently, a measured ICP above 20 mmHg is considered an indication and threshold for intervention (evidence level Grade 3, recommendation level C).^[2,8] Methods for invasive ICP monitoring include placing intraventricular, intraparenchymal, subarachnoid, subdural, and epidural catheters. Intraventricular catheterization gives relatively high accuracy and stability and is currently considered the gold standard. Besides monitoring, it can also reduce ICP by draining cerebral spinal fluid (CSF). The procedure of placing ICP microprobe placement should strictly follow aseptic technique and requirements (evidence level Grade 2, recommendation level B).^[9] Normally, the duration of microprobe placement should be no longer than 14 days. While monitoring ICP, attentions should be paid to avoid disturbance in CPP. For severe traumatic brain injury patients, major clinical guidelines recommend that CPP be kept above 70 mmHg.^[2] Evaluation of cerebral blood flow (CBF), oxygen saturation, and brain function all facilitate management of

CPP. ICP monitor can guide clinical management. Studies show that dynamic ICP monitoring is associated with a significant reduction to use hypertonic solution and hyperventilation during treatment ($P < 0.01$) (evidence level Grade 1, recommendation level B).^[10] ICP monitoring could be influenced by position change, coughing, restlessness, pressure on the jugular vein, and daily nursing procedures. Therefore, all nursing and treatment procedures should be performed gently when the head of the hospital bed is elevated to 30°, and all-together at once when possible, to avoid disturbance on ICP monitoring. Controlling of these disturbance factors could obtain a more accurate recording of ICP.

Monitoring of cerebral blood flow

Normally CBF is 45–65 ml·100 g⁻¹·min⁻¹. Low CBF could lead to anaerobic respiration. CBF is positively correlated to CPP and inversely proportional to cerebrovascular resistance. Low blood pressure or elevated cerebrovascular resistance can cause cerebral ischemia or infarction as a result of low CBF. Methods for monitoring CBF mainly include TCD, near-infrared spectrum analysis, and laser Doppler technique, among which TCD is the most widely used. It is recommended to monitor the CBF of Neurosurgical Critical Care patients in neurosurgery should be monitored for CBF (evidence level Grade 2, recommendation level A),^[11] which shows proved benefit in preventing delayed cerebral ischemia (evidence level Grade 1, recommendation level A).^[9]

Electrophysiology monitoring

It has become a common practice using electrophysiological monitoring to guide the treatment of neurosurgical critical care patients. Quantitative EEG monitoring is a good approach to evaluate the conscious level of critically ill patients (evidence level Grade 2, recommendation level B).^[12] It is recommended for hospitals to possess this facility if possible. Apart from the evaluation of patients with seizure, electrophysiology techniques like continuous EEG and evoked potential can play important roles in monitoring and treatment of patients with acute cerebrovascular diseases, traumatic brain injury, brain tumor, and CNS infections. For neurosurgical critical care patients, continuous EEG monitoring can be implemented (evidence level Grade 3, recommendation level A).^[12] For patients with severe encephalitis, EEG monitoring doesn't play an important role for etiological diagnosis. However, for patients with confusion, stupor, or coma, EEG monitoring may help to identify nonconvulsive epileptic activity (evidence level Grade 3, recommendation level A).^[13] During the monitoring process, diagnostic evaluation of the clinical prognosis can also be finished.^[14]

Neuroimaging

Recently, the development of mobile CT and intraoperative magnetic resonance imaging (MRI) has significantly advanced the understanding of the intracranial condition in perioperative and critically ill patients. Together with positron emission tomography and other functional imaging techniques, they can greatly facilitate and direct clinical treatment.

Other techniques for neuro-monitoring

The physiology, pathology, and metabolic mechanisms of brain are very complicated, especially under pathological conditions. Besides the general and macroscopic monitoring techniques above, there are more specialized techniques to help us understand the pathophysiology of either local or systematic changes in brain. These techniques include local cerebral oximetry, jugular vein oxygen saturation monitor, as well as micro-dialysis techniques, etc. However, the clinical significance of the application of any single or multiple monitoring parameters remains to be proved by basic, and clinical researches,^[8] thus currently not recommended as routine.

STRATEGY FOR THE MANAGEMENT OF INCREASED INTRACRANIAL PRESSURE FOR THE PATIENTS IN NEUROSURGICAL CRITICAL CARE UNIT

Normally, ICP is about 5–15 mmHg. The strategies for controlling increased ICP in neurosurgical critical care patients include: (1) Head position: Keep the head in midline position elevated for 30° (evidence level Grade 1, recommendation level A);^[12] (2) Avoid low blood pressure and low effective circulating volume. To monitor patient hemodynamics through CVP or Picco monitor, and to avoid low perfusion pressure induced cerebral ischemia and secondary ICP elevation (evidence level Grade 3, recommendation level C);^[15] (3) Control hypertension. For patients with primary hypertension, as long as adequate CPP is maintained, hypertension should be reasonably controlled in case of excessive CBF and associated ICP increase, which lead to higher risk of re-bleeding and hematoma enlargement (evidence level Grade 3, recommendation level C);^[15] (4) Improve airway management in neurosurgical critical care patients, closely monitor arterial blood gas, avoid hypoxemia, and maintain PCO₂ at 30–35 mmHg ideally, avoid cerebral vasoconstriction with hyperventilation, or cerebral vasodilation and excessive CBF caused by CO₂ accumulation, which would increase ICP. Keep PO₂ > 80 mmHg and SpO₂ > 95%; (5) Control body temperature within normal range or slightly lower to reduce brain metabolic rate. Therapeutic hypothermia can be applied when necessary; (6) Take necessary sedative measures to keep patients' Ramsay Sedation Score at 3–4 or Riker agitation sedation score at 3–4 (evidence level Grade 3, recommendation level C); (7) For patients with intraventricular ICP monitoring catheters, ICP level can be managed by EVD, through fine adjustment of CSF drainage rate and volume, to achieve a beneficial ICP level (evidence level Grade 3, recommendation level C); (8) Osmotic therapy. For patients with hardly controlled high ICP and associated cerebral edema and whose renal function is normal, it is recommended that the target value of osmotic therapy should be 300–320 mOsm/L. For elder patients and patients with weak or poor renal function, the target value should be 290–300 mOsm/L. Drugs for Osmotic therapy include mannitol, glycerol fructose, albumin, artificial

colloid, hyperosmotic saline, and sometimes facilitated by diuretics, etc. The best strategy for osmotic therapy should take individual ICP level, severity of cerebral edema, cardiac function, renal function, fluid management plan into consideration. Monitoring of plasma osmolality can benefit management. (9) If ICP continues to rise after the above measures, repeat head CT promptly to exclude intracranial hematoma, cerebral contusion and laceration that requires surgical intervention.

ANALGESIA AND SEDATION FOR NEUROSURGICAL CRITICAL CARE PATIENTS

Aim and significance

The aim of analgesics and sedatives in neurosurgical critical care patients is: (1) Cure or alleviate pain and discomfort of patients, reduce adverse stimulus and over-excitation of sympathetic nervous system; (2) Improve the quality of sleep, which may reduce or eliminate bad memory of illness during treatment; (3) Alleviate or eliminate anxiety, agitation or even delirium to reduce unconscious behaviors that disturb normal treatment and nursing, and to ensure patient safety; (4) Induce and maintain at low metabolic “dormancy” state for long enough, reduce all kinds of stresses and inflammations, reduce organ injury, lower metabolic rate, and reduce oxygen consumption; (5) Short-term sedation can benefit patients by better compliance to medical treatment and nursing care (evidence level Grade 3, recommendation level B).^[16,17]

Evaluation of pain and degree of sedation

Evaluation of the severity of pain

The most common evaluation method of pain is Numerical Ranking Scale (NRS), namely “10 score” pain scale (evidence level Grade 2, recommendation level C).^[18] Severity of pain is graded into different levels ranging from 0 to 10, in which 0 represents no pain at all, and 10 stands for intolerable extreme pain that patients and physicians can imagine. For patients with an artificial airway who cannot communicate, it is important to observe pain associated behaviors (movements, facial expression, postures) and physiological parameters (heart rate, blood pressure and respiratory rate). Monitor changes in these parameters before and after analgesia is also an important way to evaluate pain severity. Facial Pain Scale (FPS) grades severity of pain by 6 facial expressions and 0–10 scores, from no pain to intolerable extreme pain. Patients are asked to choose the image or number that best describes the degree of pain. FPS and NRS are well correlated and have good repeatability.

Evaluation of depth of sedation and agitation

Currently, the most commonly used clinical evaluation system of sedation include more subjective evaluation like Ramsay score, Riker Sedation Agitation Score (SAS), as well as more objective evaluations like Bispectral Index Scale (BIS).^[16] (1) Subjective evaluation of sedation and agitation: Ramsay score is the most widely used sedation scoring system clinically and is classified into six grades.

Grade 1: The patient is anxious and restless or agitated, or both; Grade 2: The patient is cooperative, oriented and calm; Grade 3: Responsive to commands only; Grade 4: Exhibiting brisk response to light glabellar tap or loud auditory stimulus; Grade 5: Exhibiting a sluggish response to light glabellar tap or loud auditory stimulus; Grade 6: Unresponsive. In the Riker SAS scoring system, sedation and agitation level are evaluated by seven different behaviors of the patients [Table 2]. However, for patients with neurological impairment, subjective score alone is not enough. (2) Objective evaluation of sedation: Currently reported methods include BIS, heart rate variability, and contraction of lower segment of esophagus, etc. These objective evaluations could be considered when possible (evidence level Grade 3, recommendation level C).^[16] Generally, a BIS value of 85–100 is considered normal, 65–85 is under sedative state, 40–65 is general anesthesia state, and lower than 40 may present as outburst inhibition.

Applications of analgesic and sedative

Analgesic

Patient with pain score ≥ 4 should initiate treatment with drugs like nonsteroidal anti-inflammatory drugs (contraindicated in allergic patients, patients with acute bleeding or peptic ulcer), nonopioids analgesic, and opioids.^[19]

Sedative

Use of sedatives should be very cautious in neurosurgical critical care patients because their clinical management involves regular evaluation and observation of consciousness. The necessity and feasibility of sedation should be thoroughly evaluated before giving sedatives. During sedation, Ramsay score or SAS score is generally 3–4 and BIS around 65–85. The sedative effects of treatment should be evaluated and recorded timely and systemically, to facilitate prompt adjustment of medication and dosage to reach and maintain an ideal sedation level (evidence level Grade 3, recommendation level C).^[16] It is generally recommended to use short-term sedatives with more controllable side effects, such as propofol, midazolam, and dexmedetomidine. For short-term (≤ 3 days) sedation, propofol and midazolam have similar clinical effects, while propofolis present faster onset (30–60 s) and shorter acting time ($t_{1/2} = 2.5$ min), which facilitate the control of sedation degree and evaluation of neurological system. Its clinical effects also include reduction of CBF, ICP, and anti-convulsive effects. Midazolam also

takes effects rapidly and similarly, while prolonged use could lead to accumulation. Dexmedetomidine is a highly selective α -2 receptor agonist targeting CNS, with both analgesic and sedative effects. Its use can help reduce the dosage of opioids. It can keep patients awake while being sedated, which greatly facilitates routine neurological examination and symptom observation. It only has mild respiratory inhibition, which facilitates to wean mechanical ventilation for neurocritical patients, thus considered promising in neurosurgical critical care.^[19] The dosage of intravenous analgesics and sedatives should gradually reach an ideal level for desired analgesia and sedation effects. It should be particularly emphasized that all the above sedatives have different degrees of respiratory inhibition effects and blood pressure reduction effects in clinical applications. However, low CPP is strongly contraindicated in neurosurgical critical care patients, therefore, the dosage of pain medicine should be properly controlled and real-time monitoring of patients' respiration and circulation should be in place (evidence level Grade 2, recommendation level C),^[19] thus being ready for potential correcting for respiratory and circulatory changes at very first time.

Special conditions

For patients with severe traumatic brain injury, use of sedatives could prevent ICP elevation (evidence level Grade 2, recommendation level B);^[20] Deep sedation could improve refractory intracranial hypertension (evidence level Grade 3, recommendation level C).^[20] Sedation is especially required for patients undergoing endotracheal intubation, ICP monitoring or central venous catheter monitoring. When necessary, continuous analgesic treatment can be used (evidence level Grade 3, recommendation level B).^[17] Severe headache after acute subarachnoid hemorrhage requires appropriate analgesia and sedation, to prevent from subsequent hypertension, tachycardia, agitation and anxiety caused by the noxious stimuli, which increase the risk of aneurysmal rebleeding. It is recommended to use a short-acting and reversible medication in this condition (evidence level Grade 3, recommendation level B).^[17] Delirium requires timely management. Haloperidol is the first-line therapy for delirium (evidence level Grade 2, recommendation level B).^[17] However ECG monitoring should be implemented during its treatment, as the drug could cause dosage dependent QT interval prolongation

Table 2: Riker SAS

Score	Term	Description
7	Dangerous agitation	Pulling at ETT, trying to remove catheters, climbing over bedrail, striking at staff, thrashing side-to-side
6	Very agitated	Requiring restraint and frequent verbal reminding of limits, biting ETT
5	Agitated	Anxious or physically agitated, calms to verbal instructions
4	Calm and cooperative	Calm, easily awoken, follows commands
3	Sedated	Difficult to arouse but awake to verbal stimuli or gentle shaking, follows simple commands but drifts off again
2	Very sedated	Arouses to physical stimuli but does not communicate or follow commands, may move spontaneously
1	Unarousable	Minimal or no response to noxious stimuli, does not communicate or follow commands

(1) Vicious stimulation: Suction of sputum or pressing eye orbit, sternum or nail bed for 5 s. (2) Artificially synthesized colloidal solution can increase the risk of renal failure, allergy, and hemorrhage. SAS: Sedation Agitation Scale; ETT: Endotracheal tube.

and increase the risk of ventricular arrhythmia. Lorazepam or midazolam can be used for delirious patients who are also anxious. For patients who cannot tolerate or have contraindication to haloperidol, antipsychotics, such as clozapine or olanzapine etc. are recommended (evidence level Grade 2, recommendation level C).^[17]

Nursing care during analgesia and sedation

Try to find out causes of patients' pain or discomfort and eliminate these noxious stimuli. If this is not possible, apply palliative care including physical therapy and psychotherapy to alleviate patients' discomfort. Initiate routine subjective and objective evaluation of analgesia and sedation effects and record them. Provide high-quality nursing care to help patients to build a healthy sleep cycle, and reduce unwanted visual and auditory stimuli to the patients.

NUTRITIONAL THERAPY FOR NEUROSURGICAL CRITICAL CARE PATIENTS

Nutritional therapy

Most of the neurosurgical critical care patients have intact gastrointestinal (GI) function, and their nutritional therapy should follow principles below.^[21-24]

Nutritional evaluation

Comprehensive and reliable nutritional evaluation for neurosurgical critical care patients cannot be fulfilled by basic evaluation parameters like body weight, serum albumin, prealbumin, etc. A more comprehensive evaluation should take clinical conditions into consideration, such as weight loss, severity of disease, past nutritional state, comorbidities, GI function, etc. The most commonly used tool for clinical nutritional risk screening and evaluation is the NRS 2002 score, and a nutritional support strategy should be based on the severity of nutritional risk (evidence level Grade 2, recommendation level B).^[25-27]

Route for nutrition support

Enteral and parenteral nutrition are both available routes for nutritional therapy. Enteral nutrition is more close to physiological conditions and is the preferred route (evidence level Grade 2, recommendation level B).^[8] Thus, an early examination of swallowing function, is necessary. Water swallow test is such a simple and easy test. However, for patients requiring prolonged enteral nutrition (>4 weeks), percutaneous endoscopic gastrostomy is preferred if possible. Patients requiring long-term enteral nutrition via gastric tube should have tube replacement regularly (evidence level Grade 2, recommendation level B). If enteral nutrition cannot meet the goal of energy requirement, parenteral and enteral nutrition can be combined to provide additional energy. In critically ill patients complicated with severe GI stress ulcer, GI bleeding, or in patients who cannot tolerate enteral nutrition, parenteral nutrition should be used for support. For patients waking up from a stroke or ruptured aneurysm, without a thorough evaluation of swallowing function, no food or even medication can be given orally. When there is any change in patient's condition, it is necessary to

re-evaluate swallowing function. For patients with impaired swallowing function, rehabilitation of dysphagia and other helpful treatments were recommended (evidence level Grade 2, recommendation level A).^[28]

Time to initiate nutritional therapy

It is recommended to initiate nutritional therapy early. Enteral nutrition should be started 24–48 h after onset of neurosurgical illness. Energy requirement should be reached within 48–72 h. Adequate nutritional support within 72 h for severe traumatic brain injury patients can improve prognosis (evidence level Grade 2, recommendation level B).^[29] For stroke patients who cannot meet nutritional requirements through diet only, it should be considered to initiate enteral nutrition support within 7 days after admission (evidence level Grade 2, recommendation level B).^[25] In terms of parenteral nutrition support, previous nutritional condition and GI function should be considered. If patients have malnutrition upon admission or there is a contraindication to enteral nutrition, parenteral nutrition should be initiated as early as possible. In addition, if the energy requirements cannot be reached in 5–7 days with enteral nutrition only, parenteral nutrition should be initiated.

Goal of energy supply

For neurosurgical critical care patients, the goal of energy supply during the acute phase should be 20–25 $\text{kal}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$. For enteral nutrition, protein accounts for 16% of the caloric goal, fat for 20–35% and carbohydrates for the rest. The ratio of calorie to nitrogen should be around 130:1. For parenteral nutrition, the lowest level of carbohydrate should be above 2 $\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ to maintain appropriate blood glucose. While venous lipid emulsion should be above 1.5 $\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$, and mixed amino acids 1.3–1.5 $\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ (evidence level Grade 2, recommendation level A).^[23]

Enteral nutrition formulation

Selection of enteral formula for nutrition support should be discussed with dietitian, taking patient's GI function (normal function, digestive or absorptive disorder, GI motility disorders, etc) and comorbidities (such as diabetes mellitus, hyperlipidemia, and hypoalbuminemia). The options include whole protein balanced formula, predigested short peptide or amino acid formula, diabetes-specific formula and high protein formula, etc. However, current evidence doesn't support that immune-regulation formula could improve the prognosis of traumatic brain injury (evidence level Grade 2, recommendation level B).^[8] Choice of formula should be qualified, balanced and individualized. The components of the formula should include macromolecular nutrients (carbohydrate, lipids and protein), electrolytes, and small molecule nutrients (trace elements, vitamins), as well as other supplemental components (such as glutamine and insulin). It is reported that after long-term tube feeding or parenteral nutrition, taurine and carnitine levels are reduced, even prokinetics could not significantly improve tolerability of feeding (evidence level Grade 3, recommendation level B).^[29] and special tolerability improved formula containing medium

chain triacylglycerol could be another option.

Rate of nutritional support

When administering enteral nutrition, infusion rate on the 1st day should be 20–50 ml/h, and could be increased to 80–100 ml/h on the 2nd day. Infusion pump can be utilized to provide better management of infusion rate according to different clinical conditions.

Monitoring and adjustment of nutritional support

The rate of nutrition supply, whether energy supply is sufficient, occurrence of complications like vomiting, diarrhea, and infections, should all be promptly evaluated, and then decide whether to adjust the nutritional support strategy accordingly.

Key points in nursing care of nutritional therapy

1. Positioning and tube placement: Elevate the head at least 30° to lower the risk of aspiration pneumonia; meanwhile, take measures to reduce the problem of shear force caused by body slipping down, to avoid pressure ulcers. Insert the gastric tube 7–10 cm beyond the measured point
2. Maintenance of the temperature of infused nutrition solution: Infusion heating measure or nutritional pump with heating system should be adopted
3. Maintenance of nutrition tube: Check the position of the tube after tube placement and every time before feeding. Routinely exam is necessary to see if there is a dislocation of tube, aiming to eliminate the risk of aspiration while feeding. To avoid tube obstruction, it is recommended to flush the tube with 30 ml warm water every 4 h, after discontinuation of the infusion, 30 min before and after administration of medicine. Keep tube sterile during nursing procedures and avoid contamination. Feeding tubes should be replaced every 24 h.

MANAGEMENT OF COMPLICATIONS IN NEUROSURGICAL CRITICAL CARE PATIENTS

Central nervous system infection

It should be emphasized that attentions paid to prevention is more important than treatment in perioperative neurosurgical patients. The following should be particularly emphasized.

1. Detailed preoperative preparation, sterile operative environment, sterile procedures and standard procedure to change dressings. Preventive antibiotics should be administered just 30 min before skin incision (evidence level Grade 2, recommendation level B)^[30] and this cannot be taken as the key to infection control. In NCCU, hand-washing regime should be carried out strictly. Regulations on nosocomial infection by ministry of health should be implemented. Establish a comprehensive hospital infection control system, including a standard procedure to identify, register, report, analysis and

provide feedback for nosocomial infection Strictly follow indications of antibiotic use (evidence level Grade 2, recommendation level B),^[31] to reduce and cut down the spread of multi-drug resistant bacteria among patients (evidence level Grade 2, recommendation level A).^[31]

2. When patients present with signs of infection, samples of CSF, sputum, urine, wound secretion, tip of deep venous catheter as well as the blood sample should be collected for pathogen culture and drug sensitivity test. For patients experiencing sudden changes in consciousness or neurological examination, as well as high fever, lumbar puncture should be performed (except contraindicated) (evidence level Grade 3, recommendation level C).^[32] When intracranial infection is highly suspected, neurological imaging should be completed (evidence level Grade 3, recommendation level B),^[32] and CSF should be collected for culture and smear, as well as routine test and biochemical analysis (evidence level Grade 3, recommendation level C).^[32] If the diagnosis of intracranial infection is confirmed, it is very important to control the infection lesion appropriately, by drainage or debridement, etc. (evidence level Grade 2, recommendation level A).^[33] For infections caused by CSF drainage or shunting, it is strongly recommended to remove the drainage or shunting devices. Re-start of shunting should not be performed until CSF cell count returns normal and repeated negative culture are obtained (evidence level Grade 2, recommendation level A).^[32,33]
3. Diagnostic criteria and method: (1) Body temperature: >38°C or < 36°C. (2) Clinical symptoms: Strong meningeal irritation sign, signs of increased ICP or with imaging evidence. It is recommended to perform normal, and contrast enhanced MRI for imaging (evidence level Grade 1, recommendation level A).^[14] If MRI is not available, contrast-enhanced head CT is recommended (evidence level Grade 3, recommendation level B).^[14] (3) Blood count: White blood cell (WBC) >10 × 10⁹/L, or neutrophil ratio >80%. (4) CSF analysis: For patients suspected of CNS infection, routine CSF analysis and pathogen culture should be performed (unless contraindicated) (evidence level Grade 3, recommendation level A).^[14] Purulent infections have typical CSF findings: Total WBC >500 × 10⁶/L or even 1000 × 10⁶/L, polymorphonuclear leukocyte ratio >80%, glucose <2.8–4.5 mmol/L (or lower than 2/3 of blood glucose level), protein >0.45 g/L, positive bacteria smear, and positive CSF bacteria culture. Meanwhile, do appropriate fungal, tumor, tuberculosis, and virus examinations when suspected (evidence level Grade 3, recommendation level B)^[33] to facilitate differential diagnosis. (5) If necessary, other body fluid samples (such as blood, sputum, stool, nasal secretions) should also be collected for smear examination or pathogen culture, biopsy tissues culture, antigen identification and PCR analysis, which may help to establish etiology

diagnosis of CNS infection (evidence level Grade 3, recommendation level A).^[14] A comprehensive analysis should take clinical epidemiology, symptoms, and laboratory diagnosis into consideration, to identify if the CNS infection is caused by homogenous pathogenic microorganism (evidence level Grade 3, recommendation level B).^[14]

4. Principle for selection and use of antibiotics: (1) Once the clinical diagnosis of infection is made, empirical antibiotic treatment should be initiated right after collecting samples for examination and cultures. Choose antibiotics according to clinical epidemiology and local antibiotic sensitivity conditions (evidence level Grade 3, recommendation level A).^[14,32,33] Empirical treatment should directly target highly suspected pathogenic bacteria (evidence level Grade 3, recommendation level A).^[16] Follow-up pathogenic results and drug sensitivity tests, and adjust antimicrobial therapy appropriately. (2) Choose antibiotics that easily penetrate blood-brain barrier are recommended (evidence level Grade 2, recommendation level B).^[33] Antibiotics should be used intravenously as far as possible (as patients usually have increased ICP, intrathecal injection via lumbar puncture is not commonly recommended. When necessary, intraventricular injection can reinforce the therapy) (evidence level Grade 3, recommendation level C).^[34] When complicated with infection involving multiple bacteria and multiple organs, combination of antibiotics should be used. (3) According to drug permeability to blood-brain barrier and individual clinical conditions, it is generally recommended that patients with CNS infections be treated with the highest clinical dosage and for a full course of treatment (2–8 weeks or longer).

Perioperative seizure

Risk factors for seizure symptoms inducing seizure include: Past history of seizure, preoperative seizure, traumatic brain injury, brain tumor, cerebrovascular diseases including spontaneous subarachnoid hemorrhage, intracranial hematoma, and arterial malformation, as well as intracranial infections such as brain abscess and parasites etc. Surgical procedures lasting longer than 4 h, brain edema or ICP elevation, postoperative hemorrhage or infections all have higher risk of triggering epileptic seizure.^[35]

1. Treatment of seizure: Anti-seizure drug (AED) treatment should be selected based on the type of seizure and possible risk factors for the patient. For patients with partial seizure (including secondary generalized seizures), carbamazepine and dilantin are the first line of choices, valproic acid and novel AEDs such as oxcarbazepine, levetiracetam, topiramate, and lamotrigine etc. can be used as second-line medication. For absence seizure, ethosuximide and valproic acid are considered first choices. For atypical absence seizure and atonic seizure, the first choice is valproic acid, lamotrigine can be the next. For myoclonic seizures,

the first-line of choices are valproic acid, lamotrigine, and clonazepam. For general tonic-clonic seizure, the first choices are valproic acid and phenytoin, novel AEDs such as levetiracetam, topiramate, lamotrigine, and zonisamide can also be used. Initiate therapy with single-drug first. If symptoms still cannot be properly managed by maximum tolerable dosage, combination of drugs should be considered. Be aware of drug interactions and side effects. When necessary, monitor blood concentration of certain drugs (carbamazepine, phenytoin, valproic acid, phenobarbital, and levetiracetam).

2. Status epilepticus: (1) Definition: Status epilepticus is defined as a continuous state lasting 5 min or longer with clinical and (or) EEG recorded epileptic activities, or repeated seizures without recovery period (evidence level Grade 2, recommendation level A).^[35] Status epilepticus is categorized into convulsive (convulsion related to rhythmic jerking) and nonconvulsive (EEG shows seizure activities but there is no clinical manifestation of convulsive status epilepticus) (evidence level Grade 1, recommendation level A).^[35] The cause of status epilepticus should be identified, and treatment be initiated as early as possible (evidence level Grade 1, recommendation level A).^[35] (2) Treatment options: Treatment of status epilepticus includes two aspects: Termination of seizure activity and treatment for underlying disease. Primary management should follow the ABC principle (airway, breathing, and circulation), and procedures include keeping airway patent, endotracheal intubation, oxygen inhalation, ECG and blood pressure monitoring etc. (evidence level Grade 3, recommendation level C).^[36] Treatment of convulsive status epilepticus should be initiated immediately after onset and be continued until the cessation of clinical seizure symptoms (evidence level Grade 1, recommendation level A)^[35] or till epileptic activity on EEG is stopped (evidence level Grade 2, recommendation level A).^[35] Benzodiazepines were used for initial emergency management (evidence level Grade 1, recommendation level A).^[3] Fast acting AEDs for controlling status epilepticus include fosphenytoin sodium/dilantin, valproic acid, or levetiracetam intravenously (evidence level Grade 2, recommendation level A).^[35] EEG monitoring is generally recommended for patients with status epilepticus when available (evidence level Grade 3, recommendation level A).^[35] Initiate continuous EEG monitoring within 1 h after onset of status epilepticus (evidence level Grade 3, recommendation level A).^[35] For comatose patients, EEG monitoring should continue for at least 48 h (evidence level Grade 3, recommendation level A).^[35]
3. Preventive AED: (1) Brain tumor: For newly diagnosed brain tumor patients (including primary tumor), AED cannot prevent the first onset of the seizure. Therefore, preventive AED is usually not prescribed for patients

with newly diagnosed brain tumor (evidence level Grade 3, recommendation level C).^[37] Brain tumor patients with risk factors of seizure should use AED after surgery. For brain tumor patients without postoperative seizure activity, especially those unstable conditions or those experiencing adverse effects of AED (evidence level Grade 2, recommendation level B), AED dosage should be gradually reduced after 1 week from surgery and then discontinued.^[37] For patients with brain tumor metastasis without seizure activity, routine preventive AED is not recommended (evidence level Grade 1, recommendation level A).^[36] Patients with previous epileptic activity can use combination of drugs when necessary, but enzyme-inducing AED should be avoided (evidence level Grade 2, recommendation level B).^[37] (2) Traumatic brain injury: For severe traumatic brain injury patients with typical presentations, preventive AED should be applied, with a loading dose intravenously after injury as early as possible, to reduce the risk of early onset seizure activity after trauma (within 7 days) (evidence level Grade 1, recommendation level A).^[38] It is not recommended to use preventive dilantin, carbamazepine, or valproic acid routinely for controlling the risk of posttraumatic late onset (after 7 days) epileptic activity (evidence level Grade 1, recommendation level A).^[38] (3) Cerebrovascular diseases: For patients without seizure activity or its subclinical onset after stroke, preventive AED is not recommended (evidence level Grade 1, recommendation level A).^[11] However, for patient with past seizure history, cerebral parenchymal hematoma, or middle cerebral artery aneurysm, preventive AED can be applied (evidence level Grade 2, recommendation level B).^[39] Patients with seizure after stroke should receive AED treatment (evidence level Grade 1, recommendation level B).^[11]

4. Key of nursing: When patients have seizure or during seizure, keep the airway clear, and turn the head to one side immediately. Record the duration and end of seizure, duration of unconsciousness, and call the physicians in time. Pay attention to the possible respiratory inhibition after giving AEDs. Intravenous infusion should be released slowly. When delivering medication, closely monitor changes in respiratory rhythm and vital signs of the patients. Once respiratory inhibition is observed, medication should be reduced in dosage or discontinued immediately.

Venous thromboembolism

Venous thromboembolism (VTE) is a common but devastating complication for neurosurgical critical care patients. It includes deep vein thrombosis (DVT) and pulmonary embolism (PE). After neurosurgery, patients have a 19–50% incidence of DVT and 1.5–5% for PE. The incidence of VTE in different types of neurosurgical diseases vary. In traumatic brain injury patients, incidence of DVT is 20% while in subarachnoid hemorrhage it is 1.5–18% and

32% for brain tumor patients.^[40,41]

Risk factors

Dehydration; stroke, paralysis; severe infection, immobilization; severe pulmonary diseases, hormonal replacement therapy, heart failure and its inactive state, spinal cord injury, central venous catheterization, malignant tumor, surgery and tissue injury, repeated minor trauma, and venous dysfunction etc. Besides common risk factors for VTE like slow blood flow, vessel wall injury, hypercoagulability, there are special risk factors for neurosurgical critical care patients, such as long duration of operation (>4 h), use of glucocorticoid, release of procoagulation factors locally during brain surgery, hemi-paralysis after surgery, long time immobilization, osmotic dehydration etc. Operating time >4 h can double the risk of DVT for neurosurgical patients.^[42]

Diagnostic tests

Include imaging study and laboratory tests. Imaging study is mainly by Doppler ultrasonography and venography. Laboratory tests mainly include tests for hypercoagulability and D-dimer, etc. Negative serum D-dimer is significant for excluding acute PE in patients with low risk. Thus, a negative D-Dimer is one of the most valuable tests to exclude PE. But the sensitivity and specificity of D-dimer alone are relatively low (evidence level Grade 2, recommendation level C).^[42] Venous color Doppler ultrasonography is the gold standard for diagnosis of DVT (evidence level Grade 1, recommendation level A).^[43] Bedside color Doppler can be used routinely to screen for DVT, it is also the first choice for confirming suspected VTE (evidence level Grade 3, recommendation level C).^[43] If the first scan is negative or uncertain while VTE is highly suspected clinically, or the symptoms remain unrelieved. Ultrasonography needs to be repeated.^[42] Venous angiography should be performed when necessary. Pulmonary artery CT angiography is currently the gold standard for diagnosis of PE (evidence level Grade 2, recommendation level A).^[43] For all patients with VTE, a comprehensive clinical history and physical examination should be recorded, to identify potential factors promoting thrombosis and to evaluate if thrombolysis is appropriate (evidence level Grade 3, recommendation level C).^[43]

Prevention and treatment

Prevention of VTE should be as early as possible. Currently, the methods for prevention include physical prevention and medications. Early mobilization can reduce the risk of VTE. Physical prevention can increase venous blood flow of lower limb and reduce venous blood retention. Physical prevention includes intermittent inflating pneumatic compression (IPC) and elastic compression stockings. IPC can significantly reduce the incidence of DVT (evidence level Grade 1, recommendation level A).^[44] Medical prevention mainly includes unfractionated heparin (UFH) and low molecular weight heparin (LMWH).^[42] But neurosurgical patients may not be suitable for heparin anti-coagulation considering its relatively high risk of bleeding and drug

reactions (such as heparin induced thrombocytopenia). These patients can use novel nonheparin anticoagulants (such as recombinant hirudin, argatroban) (evidence level Grade 2, recommendation level B).^[43] For patients who have contradiction to any anticoagulant, inferior vena cava filter should be placed to avoid PE (evidence level Grade 2, recommendation level B).^[43] It should be reminded that there is a risk of bleeding to use UFH and LMWH. LMWH or UFH should not be used as prevention for patients with un-ruptured aneurysm or patients waiting for surgery (evidence level Grade 3, recommendation level A).^[44] Only, when 24 h after surgery on the aneurysm, prevention with UFH should be started (evidence level Grade 2, recommendation level A).^[43] UFH and LMWH should be discontinued 24 h before intracranial surgical procedure (evidence level Grade 2, recommendation level A).^[43] Use of antiplatelet therapy for treatment of patients with ischemic stroke can prevent DVT/PE (evidence level Grade 1, recommendation level A).^[26] A preventive dosage of LMWH or UFH can be cautiously used for acute stroke patients with high risk of DVT/PE (evidence level Grade 2, recommendation level B).^[26] However be highly alert to the risk of bleeding.

Management of body fluid

The aim of the management of body fluid for neurosurgical critical care patients is to maintain CPP and normal ICP. The followings are recommended.

Post-injury and perioperative fluid intake

Studies have confirmed that there was no statistically significant difference regarding the incidence of refractory high ICP between patients with adequate fluid infusion and patients with restricted infusion volume (evidence level Grade 2, recommendation level C).^[45] However, excessive fluid infusion may lead to pulmonary edema (evidence level Grade 3, recommendation level C).^[46] Therefore, fluid supplement should be individualized, adequate but not restricted. Nonstandard fluid supplement could increase mortality.^[44] It is recommended that CVP should be routinely monitored for patients. For patients with severe traumatic brain injury, maintain isovolumic or slightly hypervolumic state; for patients with subarachnoid hemorrhage though, it is appropriate to maintain an isovolumetric state (CVP 5–8 mmHg). In addition, if the patients suffer from cerebrovascular spasm, hypervolumetric state should be maintained (CVP \geq 8 mmHg) (evidence level Grade 3, recommendation level C).^[17] Excessive fluid supplement should be avoided for perioperative patients (evidence level Grade 2, recommendation level B).^[44]

Fluid supplement: timing and scheme

When dealing with patients in hemorrhagic shock caused by multiple traumas, one principle should be followed: Try to reach the target fluid volume as early as possible. As for options of fluid, it is generally recommended that large amount of crystalloid solution be used in early phase, but direct use of vasoconstrictors is not recommended. It has been proved that early application of vasoconstrictor increases mortality.^[9] Patients with inadequate blood volume

supplement tend to develop cerebral ischemia. Isotonic crystalloid solution is cheaper, easily obtained, and has fewer side effects; it is recommended for patients with blood volume supplementation \leq 50 ml/kg (evidence level Grade 2, recommendation level B).^[17] For patients requiring substantial blood volume supplementation over 60 ml/kg, colloidal solutions can be used in addition to crystalloid solutions. Colloidal solutions commonly include albumin, hydroxyethyl starch, gelatin solution, and dextrose injection, etc. (evidence level Grade 2, recommendation level B).^[44] Mannitol can raise plasma osmotic pressure immediately thus reducing ICP at a minimal dose of 0.25–1 g/kg. The infusion rate should be adjusted according to the patient's condition targeted with the plasma osmotic pressure at 300–320 mOsm/L (evidence level Grade 2, recommendation level B).^[47] Hypertonic saline can reduce total input of fluid, improve intraoperative fluid circulation and reduce ICP. Its effect on lowering ICP is faster and lasts longer than that of mannitol. In addition, it still works when mannitol is ineffective. When hypertonic saline is used to lower ICP in the clinic, serum sodium and urine volume should be monitored. Maintaining serum sodium at 145–155 mmol/L, plasma osmotic pressure at 300–320 mOsm/L, and potassium concentration within the normal range.

Administration of glucocorticoids

The principles of steroid use differ according to patients' conditions. All the patients receiving steroid treatments should be monitored for blood glucose. Steroid is not recommended for cerebral edema in patients with cerebral infarction (evidence level Grade 1, recommendation level A).^[48] Large dose of steroid is not recommended for patients with cerebral trauma either (evidence level grade 1, recommendation level A).^[2] Steroid can be used for patients with edema around intracranial tumors such as meningioma, glioma, and metastatic carcinoma. Dexamethasone the first choice (evidence level Grade 2, recommendation level B).^[47] To reduce side effects and interactions with other drugs, steroid should be used with minimal dosage and for a short period if possible.

Blood glucose control

Hyperglycemia would worsen the situation and lead to poor prognosis and increased mortality. On the other hand, hypoglycemia should be avoided as well (blood glucose $<$ 4.4 mmol/L) (evidence level Grade 1, recommendation level A).^[11] Blood glucose should be monitored regularly. The blood glucose of perioperative patients should be maintained at around 5–7.2 mmol/L, PPG 2 h \leq 10 mmol/L (evidence level Grade 1, recommendation level A).^[49] Be cautious about diabetic ketoacidosis and hyperosmotic nonketoacidosis caused by uncontrolled blood glucose.

Special types of water and electrolyte disturbance

(1) Central neurogenic diabetes insipidus: Cerebral trauma and other intracranial diseases can result in hypothalamus and pituitary injury, which may impair the function of the posterior lobe of the pituitary gland that regulates antidiuretic hormone (ADH) storage and secretion. It is featured by diluted polyuria and hypernatremia. In early stage, polyuria can last for hours to days. After 5–6 days, urine output

approaches normal level, which can be produced by the release of stored ADH. In late stage, ADH depletion and loss of function of hypothalamus-pituitary ADH-secreting cells, may lead to permanent polyuria. Diagnosis is based on: Medical history, symptoms and signs of dehydration and polyuria, reduced urine specific gravity and urine osmotic pressure on lab tests, hypernatremia, and elevated plasma osmotic pressure (>295 mOsm/kg). Principle of treatment: Correct insufficient ADH, supplement body fluid, and promote sodium absorption concurrently, to keep body fluid balance. During acute phase, exogenous ADH can be used, including hypophysin, desmopressin, and lypressin. Keep fluid volume at the appropriate level. Fluid such as low-sodium solution (0.45% NaCl) can be administered orally or intravenously, with low sodium solution (0.45% NaCl). (2) Syndrome of inappropriate ADH secretion (SIADH): Traumatic brain injury and other intracranial diseases and even lung cancer, result in excessive ADH secretion, presented as oliguria (400–500 ml/24 h), elevated urine sodium, reduced serum sodium, weight gain due to water retention, and relative increase of total free water content. Patients exhibit symptoms of delirium, ataxia, seizure, hyper-reflex, hypo-reflex, coma, or irreversible cerebral damage. Diagnosis is based on: Medical history related to SIADH, neuropsychiatric symptoms and signs related to hyponatremia, Serum sodium <135 mmol/L, serum osmotic pressure <275 mOsm/kg, urine sodium >25 mmol/L, and urine osmotic pressure higher than plasma osmotic pressure, etc. Principle of treatment: Restrict fluid infusion volume (<1000 ml/24 h); Supplement sodium at low speed when use hypertonic saline (3% NaCl). Diuretics and lithium can be used to inhibit the response of renal tubules to ADH. (3) Cerebral salt wasting syndrome (CSWS): This syndrome is commonly seen in traumatic brain injury and other intracranial diseases, however, its mechanism remains unclear. Its clinical manifestation is similar to that of SIADH, mainly including a triad of hyponatremia, dehydration and hyper urine sodium (>50 mmol/L). Blood volume is believed to be the major difference between CSWS and SIADH. Patients with SIADH manifest as dilution induced hyponatremia as a result of increased circulating volume. Appropriate goal of treatment should aim at controlling the circulating volume. On the contrary, CSWS would lead to a state of low circulating volume and low serum sodium. Therefore re-establishing normal circulating volume by infusing isotonic sodium solution is the major goal of the treatment, rather than restricting input.

Management of the respiratory system

Respiratory support for neurosurgical critical care patient is extremely important. Hypoxemia and hypotension are major causes of secondary brain injury. Meanwhile, neurological injury can result in centrally related disorder in respiratory rhythm, and difficulty in self-maintenance of airway. The following basic principles of mechanical ventilation for ICU patients should be followed in neurosurgical critical care patients. Applied references include Chinese Guideline for clinical application of mechanical ventilation > by Critical

Care Medicine Society of Chinese Medical Association,^[50] and Expert Consensus on clinical application of noninvasive positive pressure ventilation by Division of Respiratory Physiology and Intensive Care, Chinese Society of Respiratory Diseases.^[51]

1. The quality control and evaluation of mechanical ventilation in NCCU should meet the standards in specialties of critical care medicine and respiratory medicine, etc.
2. When using mechanical ventilation therapy, it is necessary to establish regulations on artificial airway management and strategy for prevention of ventilation related pneumonia
3. When complicated with pulmonary diseases or chest trauma, ask for consultation from related departments for diagnosis and differential diagnosis of the primary diseases, and initiate appropriate treatments accordingly
4. Medical and nursing staff in NCCU should receive systemic training in rescue, noninvasive ventilation, as well as management of ventilator related pneumonia (evidence level Grade 3, recommendation level C)^[51] and master its epidemiology, risk factors and the influence on prognosis (evidence level Grade 2, recommendation level B)^[52]
5. For NCCU patients, a thorough evaluation of respiratory condition includes: Age, history of smoking, related respiratory diseases, duration of surgery, conscious level, respiratory rhythm, ability of sputum clearance, presence of glossocoma, ventilation and exchange capacity of the lung, concomitant chest injury, inhaled oxygen concentration and recognize abnormal respiratory changes in time.^[51] During evaluation, pay attention to arterial blood gas, tissue oxygen, and end-expiratory CO₂. Adjust the mode and parameters of respiratory support accordingly
6. Evaluate the airway condition before initiating respiratory support, and establish artificial airway appropriately. During respiratory support, special attention must be paid to the effects on CNS, and the coordination of mechanical and autonomic ventilation
7. Parameters of ventilator should be set to maintain SpO₂ $>95\%$, PaO₂ >80 mmHg, PaCO₂ 35–45 mmHg (30–35 mmHg during hyperventilation). If SPO₂ is $<90\%$ and PaO₂ is <60 mmHg, the brain will experience tissue hypoxia. Although hyperventilation produced low PaCO₂ can reduce ICP, it is not recommended for long-term use because contraction of vessels could also result in cerebral ischemia. On the other hand, for NCCU patients with acute pulmonary injury, it is recommended to use a protective strategy for pulmonary ventilation with small tidal volume and medium PEEP. Intra-pleural pressure can be increased by PEEP, which leads to reduced intracranial venous return and elevated ICP. When PEEP is over 15 cm H₂O, there will be a significant effect on ICP. So a PEEP over 15 cm H₂O is only used in controlling severe hypoxemia
8. Chocking or esophageal reflux should be avoided

for patients with cerebral hemorrhage or un-ruptured aneurysm. For patients on mechanical ventilation requiring sputum suction, a short period of hyperventilation can be given first. During the process of sputum suction, avoid discontinuation of mechanical ventilation (evidence level Grade 2, recommendation level B).^[17] Keep the airway suction procedure strictly under 15 s (evidence level Grade 2, recommendation level B).^[17] Avoid saline flushing of the airway if possible (evidence level Grade 2, recommendation level B).^[17,51]

9. After establishing artificial airway, there will be stimulations of the tracheal wall by inflated air balloon, and inhalation of cold, dry air. Both of which may induce hypersensitivity of the airway. If these cannot be safely controlled, bronchial antispasmodics and budesonide nebulizer can be used
10. Invasive mechanical ventilation requires air heating and humidification during the whole process. Humidification should be kept at 33–44 mg H₂O/L and heating should be maintained at 34–41°C (evidence level Grade 2, recommendation level B).^[50] Heating and humidification can avoid implantation of mechanical ventilation related bacteria. They ensure a reasonable humidity of the airway but cannot prevent ventilator related pneumonia (evidence level Grade 1, recommendation level A)^[50]
11. During mechanical ventilation, oral care (or nonoral antibiotics) can reduce the incidence of ventilator-related pneumonia (evidence level Grade 1, recommendation level A).^[50] Routine oral care is generally recommended (evidence level Grade 1, recommendation level A).^[51] It is necessary to evaluate the respiratory support regularly, to ensure that the mechanical ventilation is appropriate and make necessary adjustments accordingly. If the patient cannot be awakened shortly after a systemic evaluation, tracheotomy should be performed when necessary
12. For patients with an artificial airway, there must be daily evaluation for: Position of the airway, whether it is clear, and if fixed reliably. For patients less tolerable to the artificial airway, sedative and analgesic should be given to avoid agitation and subsequent ICP elevation
13. Indication of the ventilator removal includes results from a comprehensive evaluation of respiration, circulation, and CNS conditions.^[53] When ready for respirator wean, a clear strategy for stopping ventilation should be made, steps by step, to avoid unnecessary risk of failure. Effective use of sedatives and shortened duration of mechanical ventilation increase the success rate of respirator removal
14. Removal of the artificial airway should not only meet the requirements of mechanical ventilation, but also necessary to consider the conscious level, whether the expectoration ability could meet the requirements for his own sputum clearance, etc. Try to remove artificial airway if requirements are met, to reduce or avoid its complications

15. When artificial airway is removed, closely observe the respiratory condition of patients and symptom development. Dyspnea is most commonly seen in airway hypersensitivity or laryngeal edema. When this happens, identify the cause first, then symptomatic treatments like intravenous bronchial antispasmodics and budesonide nebulizer can be given as support. However, if symptoms continue, noninvasive ventilation sequential therapy should be performed, or artificial airway re-established for invasive ventilation if necessary

Management of the circulatory system

Severe traumatic brain injury is often complicated with unstable hemodynamics. Low blood pressure is an independent risk factor leading to poor prognosis after severe traumatic brain injury.

1. Management of the circulatory system affects the recovery and prognosis of neurosurgical critical care patients.^[54,55] Function of major organs should be evaluated daily, to avoid ongoing organ function injury or failure due to insufficient tissue perfusion. Methods for evaluation are described in Clinical Guideline for Resuscitation of Hypovolemic Shock^[56] and Hemodynamic Monitoring and Support for Severe Infection and Septic Shock in Adult Patients^[57] prepared by Chinese Society of Critical Care Medicine. When evaluation of circulation state suggests insufficient tissue perfusion, low circulating volume or any related risks, volume resuscitation, and hemodynamic monitoring should be applied first
2. When there is fluctuation in circulation, precise precipitating factors must be found out and eliminated at the same time of establishing adequate circulation support.^[42] In addition, mean arterial pressure should be maintained above 80 mmHg to avoid cerebral ischemia
3. Circulatory system should be evaluated daily. Record fluid intake and output every hour and daily. Avoid circulation fluctuation that may cause organ function damage, and ensure adequate tissue perfusion
4. In NCCU, CPP and blood flow monitoring should be established. Keep mean arterial pressure no <80 mmHg before ICP monitoring so that optimal CPP can be guaranteed. Monitor oxygen metabolism and function of the brain should be established if available. Anemia is the most common secondary changes after severe head injury, which should be avoided if possible. Hemoglobin should be maintained ≥ 100 g/L (or hematocrit (HCT) ≥ 0.30). Hypertension secondary to traumatic brain injury happens at times. Generally, hypertension is a physiological response to insufficient intracranial perfusion. However, blood pressure should be decreased if SBP is maintained over 180 mmHg (or mean arterial pressure over 110 mmHg). If intracranial monitoring is available, manage blood pressure according to CPP.

Management of the digestive system

Due to long-term stress and stimulation from inflammatory factors, the GI blood flow is slowed in NCCU patients.

Insufficient blood supply can lead to GI ulcer, bleeding, as a result of ischemia and necrosis in local mucosa. Meanwhile, prolonged braking makes intestinal peristalsis slowed, which can easily cause GI motility disorders. Therefore, routine management of the digestive system is necessary.^[55]

1. Risk factor of stress ulcer: The risk factors of stress ulcer in NCCU include: GCS <10; mechanical ventilation over 48 h; severe traumatic brain and spinal cord injury; surgery duration >4 h; application of anticoagulants; high dosage of glucocorticoid; past history of GI bleeding within 1-year; after cardiac, respiratory or cerebral resuscitation; shock; severe ICP elevation; intracranial infection; ischemic or hemorrhagic stroke
2. Prevention with medications: Medical prevention should be individualized based on risk factors, GI function, insurance condition and adverse reaction to drugs (evidence level Grade 3, recommendation level C).^[55] Prevention medications mainly include proton pump inhibitor (PPI) (evidence level Grade 1, recommendation level A),^[55] H₂ receptor antagonist (evidence level Grade 1, recommendation level A),^[55] gastric mucosa protective agents (evidence level Grade 1, recommendation level A).^[55] Studies showed that, compared with H₂ receptor antagonist, use of PPI significantly reduces the risk of GI bleeding (evidence level Grade 1, recommendation level B). While H₂ receptor antagonist has significantly better preventive effects than gastric mucosa protective agents or antiacids. There is no significant difference on preventive effects between the gastric protective agents and antiacids. Generally, alkaline antiacid is not recommended for prevention (evidence level Grade 1, recommendation level A).^[56] Duration of using preventive medication is generally recommended as 3–7 days. More risk factors suggest longer course of preventive therapy (evidence level Grade 1, recommendation level A).^[56] For patients with recurrent bleeding, first identify the cause and then initiate treatment accordingly
3. Nonmedication prevention: Enteral nutrition should be initiated as early as possible. Early enteral nutrition can shorten the course of preventive medications. But there is no enough evidence supporting the preventive effect if enteral nutrition is used alone
4. Diagnosis and examination of stress ulcer and bleeding: If patients have coffee-like or bloody gastric fluid or tar stool, combined with findings in complete blood count parameters like hemoglobin, red blood cell (RBC), HCT, mean cell volume and hemodynamic changes, a diagnosis could be made whether there is GI bleeding resulting from stress ulcers. The site of bleeding, whether upper or lower GI bleeding and the severity can also be estimated
5. Treatment for stress ulcer and bleeding: (1) Depending on the severity of GI bleeding, monitor blood pressure, hemoglobin, RBC count dynamically, and adjust therapeutic strategy according to hemoglobin level. Also, be aware of the laboratory value deviation in

hemoglobin due to substantial fluid infusion. If there is massive bleeding from GI stress ulcers, ask for a consultation from related departments and initiate therapy with PPI to achieve acid control and hemostasis. Stop enteral nutrition if necessary, continue with gastric decompression, monitor gastric fluid pH and apply local hemostasis appropriately. (2) For neurosurgical critical care patients complicated with primary diseases like giulcer, gastric, esophageal varices, if massive upper GI bleeding occurs, perform emergency gastroscopy and endoscopic hemostasis.

ETHICS OF NEUROSURGICAL CRITICAL CARE MANAGEMENT

Most neurosurgical critical care patients present with coma, aphasia, delirium, or other changes in consciousness, and thus becoming incapable of making decisions. Under these circumstances, patients' authorized proxies should have the responsibility to determine the treatments and monitoring.

Evaluation of patients' competence “(decision-making ability)”

“Decision-making ability” refers to the capacity of patients to make and claim their reasonable options after comprehensive consideration. Patients intubated, comatose, or hemisphere aphasic have no ability to make decisions. Some patients may have poor capacity to make decisions according to the degree of consciousness and stage of disease. Therefore, the physicians are responsible to evaluate almost all the patients. When patients lose their decision-making ability, communication with their family or authorized proxy is necessary. Else, another physician should be invited to evaluate the patient's competence together.

Informed consent to treatment

Many patients would be treated with invasive procedures. Before any operation, consent should be obtained from the patient or his/her proxy. The patient should be provided with enough time and information to understand the situation well before any decisions are made (except for emergency). Related information offered by physicians should include: Diagnosis, patient's general condition, aim and successful rate of the operation as well as risks, and alternative treatments. If necessary, medical professionals should help to bring about an agreement between the patients and families, following the principle of “do no harm.”

Consent of human body study

The criteria for informed consent for scientific research should be stricter than that of clinical treatment. Potential risks from research should not go beyond possible benefits. And the procedures should follow the guidelines or consensus strictly.

Emergency treatment principle without informed consent

Under emergent situation, patients may lose their competence, and waiting for consent from authorized proxy would cause the patient to lose his/her best opportunity for treatment thus being hurt. To avoid this from happening, informed consent should be obtained from the patients or authorized proxy in advance (which is called the general informed consent). Under emergency and when it is necessary to change treatment strategy, patients or their proxy don't have to be informed about the risk and benefit. This strategy has to be planned carefully, and the approval has to be obtained first.

Patients without caretakers or custody

All incompetent patients should have rights to authorize their proxy to make decisions. If the patients have no proxy, the medical professionals are responsible to make the decision to obtain the best prognosis of the patients. However, medical and nursing professionals should do their best to seek supports from patient's family, close friends, or institute/society/law.

Establish supplementary regulations such as those related to visiting as well.

FRAMEWORK AND PROFESSIONAL TRAINING FOR NEUROSURGICAL CRITICAL CARE UNIT SYSTEM

Critical patients in neurosurgery had the characteristics of both patients in neurosurgery and those of critical patients. Therefore, it is recommended that NCCU adopt collaboration modality of multi-disciplinary team.

Physician team building and training

The team includes physicians from neurosurgery, critical care medicine, neurology, emergency medicine, and anesthesiology, etc. If possible, physicians from rehabilitation, dietitian, and respirator operators should get involved as well. The ideal mode is an independent NCCU. Neurosurgical critical care subgroup in collaboration with comprehensive ICU would be an alternative choice. Physicians in NCCU should be able to lead the monitoring team and work with neurosurgeons, establish and implement all clinical and management regulations of NCCU, closely collaborate with nursing care and other professionals and play a connecting role in all services of the monitoring ward. Meanwhile, the physician team should be trained in critical care medicine as well as neurosurgery. NCCU in China would be optimized in the future in the aspects of professional team, strict training, and certification regulations.

Nursing team and its training

Nurses at NCCU should be with strong sense of responsibility, profound insight, carefulness, clear thinking, rapid response, team spirit and good at communication. Self-adjustment and good physical condition are indispensable. The nursing care professionals should be double-trained for critical nursing care and neurosurgery nursing care. In this way, a nursing care team should master basic theoretical knowledge and skills of critical care, as well as specific theoretical knowledge and skills of neurosurgery, thus has a comprehensive ability of caring critical patients in neurosurgery.

In conclusion, neurosurgical critical care is a burgeoning interdisciplinary subspecialty with great potential of development. As known, the success of neurosurgery requires not only great surgical techniques, but also comprehensive perioperative managements and supports by the entire clinical team. Neurosurgeons and physicians need to be aware of the importance of critical care in neurosurgery. Standard training and regulations are the focus and trend of the future.

This consensus aims to standardize routine treatment procedures, to update common sense in neurosurgical critical care, and to achieve better clinical prognosis. It was organized by the Chinese Neurosurgery Society, in which outstanding experts in neurosurgical critical care were invited to formulate the consensus. We understand that different regions have different conditions and levels of NCCU management. But all hospitals should follow the normative consensus as much as possible according to their present situations.

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