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Topical Review

Fellowship Training in the Emerging Fields of Fetal-Neonatal Neurology and Neonatal Neurocritical Care

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ABSTRACT

BACKGROUND: Neonatal neurocritical care is a growing and rapidly evolving medical subspecialty, with increasing numbers of dedicated multidisciplinary clinical, educational, and research programs established at academic institutions. The growth of these programs has provided trainees in neurology, neonatology, and pediatrics with increased exposure to the field, sparking interest in dedicated fellowship training in fetal-neonatal neurology. **OBJECTIVES:** To meet this rising demand, increasing numbers of training programs are being established to provide trainees with the requisite knowledge and skills to independently deliver care for infants with neurological injury or impairment from the fetal care center and neonatal intensive care unit to the outpatient clinic. This article provides an initial framework for standardization of training across these programs. **RESULTS:** Recommendations include goals and objectives for training in the field; core areas where clinical competency must be demonstrated; training activities and neuroimaging and neurodiagnostic modalities which require proficiency; and programmatic requirements necessary to support a comprehensive and well-rounded training program. **CONCLUSIONS:** With consistent implementation, the proposed model has the potential to establish recognized standards of professional excellence for training in the field, provide a pathway toward Accreditation Council for Graduate Medical Education certification for program graduates, and lead to continued improvements in medical and neurological care provided to patients in the neonatal intensive care unit.

Keywords: neonatal neurocritical care, neonatal neurology, fetal neurology, fellowship, education, neonatology, neurophysiology, neuroradiology

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Introduction

Over the past several decades, increased understanding of the developing brain and the short- and long-term

neurological morbidities faced by surviving infants has led to fundamental alterations in medical and neurological care provided in the neonatal intensive care unit (NICU).^{1,2} Novel neuroprotective strategies to prevent and/or mitigate the effects of brain injury and improve neurological outcomes have been established and implemented.¹⁻³ Ancillary testing that requires age-specific interpretation, such as electroencephalography (EEG) and magnetic resonance imaging (MRI), has become commonplace. New and increasingly available neurodiagnostic technologies to

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identify and evaluate neurological impairment have been developed and adapted. As a result, neonatal neurocritical care has emerged as one of the most rapidly evolving subspecialties in all of medicine.

Concomitant with these advances in NICU clinical care, several centers have established dedicated integrative fetal-neonatal neurology clinical and research programs.^{1,2,4-7} At most centers, these programs consist of multidisciplinary collaborations including neurology, neonatology, neurosurgery, neuroradiology, palliative care, and obstetrics. The advent of these programs distinctly changed the clinical practice of neonatal neurocritical care. Protocols for consistent and comprehensive evaluation and management of common neurological conditions have been developed. Specialty consultants are involved earlier and more frequently, often as early as fetal consultation. Electrophysiological and radiological testing adapted for the developing brain are used to evaluate patients and develop individualized care plans. Furthermore, neonatal neurologists are playing an increasing role in rigorous neonatal follow-up programs. The overarching result has been establishment of a brain-directed model of critical care and improvements in patient care and family relationships.⁶⁻⁸ Subsequently, as many as one third of all NICU patients at some institutions are evaluated by neonatal neurocritical care programs, leading to 100s of encounters each year at large academic centers.² As a result of this growth, neurocritical care programs of this type have become financially beneficial.⁹

The growth of these clinical programs has provided trainees in neurology, neonatology, and pediatric training programs with consistent and expanded exposure to neonatal neurocritical care as an important component of their training, sparking growing interest in training in the field.¹⁰ Increasingly, specialized training beyond the traditional residency program is required to attain the requisite experience and expertise necessary to function independently and provide state-of-the-art care in this area of child neurology.¹¹ This requirement has led many individuals to pursue additional training in fetal-neonatal neurology, often through independent mechanisms. In an attempt to meet these growing clinical and training demands, increasing numbers of training programs in fetal-neonatal neurology have been established through varied funding mechanisms. Some institutions have capitalized on local neurocritical care programs in adult and pediatric medicine, where training opportunities have been established over the last decade.¹² Certification in Critical Care Neurology is now offered through the United Council of Neurological Specialties¹³; however, there is currently no formal accreditation for fetal-neonatal neurology and neonatal neurocritical care.

This article represents an initial step toward standardization of training in fetal-neonatal neurology and neonatal neurocritical care. We include recommendations regarding goals and objectives for training in the field, core areas where clinical competency must be demonstrated, recommended training activities, neuroimaging and neurodiagnostic modalities that require proficiency, and programmatic requirements to support a comprehensive and well-rounded training program. Although newly established training programs will likely differ based on

local program structure and resources, these recommendations (developed based on our own existing programs and consensus agreement where programs differ) can be used as foundation for establishment and continued development of programs at individual institutions.

Overall goals and objectives

The overarching goal of fetal-neonatal neurology fellowship training should be to successfully provide instruction for physicians—including both child neurologists and neonatologists—in the knowledge and skills necessary to practice as a specialized consultant and collaborator in the care of neonates with or at risk for neurological injury or impairment in the NICU.

To achieve this, the trainee must acquire comprehensive medical knowledge in the diagnosis and management of neurological conditions affecting neonates, including conditions arising during fetal development and as a result of preterm birth. This includes expert skills in neurological examination of the newborn at all gestational ages. Also needed is knowledge in neuroembryology, etiologies of brain injury, genetic and metabolic conditions, neuromuscular diagnoses, and epilepsies presenting in the antenatal, perinatal, or early postnatal period. Knowledge of the primary newborn medical conditions that accompany these neurological conditions and their therapies is also essential (e.g., respiratory failure, pulmonary hypertension, etc.). Expertise in the interpretation and integration of results from diagnostic modalities in common use in the NICU is important. Understanding of current treatment options in the treatment of newborns and young children is also required. This knowledge should enable the graduate to provide counseling of families antenatally, care and support of newborns and families during the neonatal period in the NICU, and continued ongoing assessment and management of NICU graduates in follow-up.

To this end, the fetal-neonatal neurology fellowship must provide adequate exposure and supervised training in neurological patient care from the fetal care center or NICU to the outpatient clinic settings. Postnatal care in the neonatal neurology follow-up clinic should be established in collaboration with rehabilitation services and developmental pediatricians and include exposure to complex follow-up care for developmental delay and epilepsy, as well as cognitive, behavioral, and neuromotor disabilities. Focused training on neurophysiological and neuroimaging tools is also needed. Education in patient-centered care, ethical and humanistic aspects of care, communication skills, and palliative care is also of high importance in a field where parents are faced with life-changing diagnoses for their yet unborn or newborn child. The framework must also exist to enable the trainee to gain exposure to clinical or basic science research in neonatal neuroscience, to provide opportunities for ongoing contribution to the field of fetal-neonatal neurology, and to develop the skills for evidence-based practice and learning.

Although there is currently no accreditation for training in neonatal neurocritical care in the United States or Canada, these activities should be centered on federal guidelines (Accreditation Council for Graduate Medical Education [ACGME] or Royal College of Physicians and Surgeons of

Canada, respectively), focusing on the hallmark components of patient care, medical knowledge, practice-based learning and improvement, interpersonal and communication skills, professionalism, and systems-based practice to provide the framework for future accreditation.

Core competencies

Most trainees will arrive in neonatal neurology fellowship programs having completed core programs in pediatric neurology or neonatology. Yet, with the expansion of neonatal neurocritical care programs, there is also increasing interest from other specialty pathways including cardiac intensive care and developmental pediatrics. Given the heterogeneity of pre-fellowship training, all trainees must develop proficiency in a number of key areas directly related to fetal-neonatal neurology (Table 1).^{2,4,7,13–16} These competencies should be developed as they relate to the fetus where applicable and in a postmenstrual age-specific manner in the care of term and preterm neonates.

Principal among these is the ability to perform a neurological examination in a critically ill newborn, recognize the acute versus subacute versus chronic neurologically affected newborn, and become confident at independently diagnosing and managing common neurological conditions (Table 2). The trainee must also develop a level of comfort in imparting information regarding these diagnoses to families to aid them in acute decision-making and forming long-term care plans in collaboration with the maternal-fetal medicine or ICU teams.

Recommended training activities

Recommended activities include direct patient care balanced with formal didactic education and subspecialty rotations (Table 3). Across all activities, programs should develop a detailed set of learning objectives to provide the trainee with understanding of the skills and knowledge they are to acquire.

TABLE 1.
Core Competencies

<ul style="list-style-type: none"> • Perform age-appropriate neurological examinations • Diagnose and manage common and rare neonatal neurological disorders • Understand the pathophysiology of common conditions and mechanism of action of neuroprotective therapies • Understand proper use of ancillary neurodiagnostic and neuroimaging tools to improve assessment, management, and prognostication (see Neurodiagnostic and neuroimaging tools requiring proficiency section) • Synthesize available clinical information to predict neurological outcomes • Understand evidence-based medicine as it applies to fetal and neonatal neurology, including current guidelines and practice parameters • Be sensitive to ethical issues that arise in fetal-neonatal neurology • Develop effective communication skills with families and other health care providers
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TABLE 2.
Commonly Encountered Fetal and Neonatal Neurological Conditions

<ul style="list-style-type: none"> • Neonatal encephalopathy/hypoxic-ischemic encephalopathy • Seizures, acute symptomatic seizures and neonatal onset epilepsies, as well as status epilepticus • Stroke, arterial and venous • Intracranial hemorrhage, including intraventricular hemorrhage • White matter injury • Neurological sequelae of congenital heart disease and critical illness • Meningitis/encephalitis and <i>in utero</i> infections • Hypotonia/neuromuscular disorders • Hydrocephalus, posthemorrhagic and congenital • Inborn errors of metabolism • Neurogenetic and complex malformation syndromes • Brain malformations and cerebral vascular malformations

Inpatient training

Inpatient training experience with the neurocritical care service is necessary for the trainee to master the evaluation and management of acute and/or subacute neonatal neurological conditions. The trainee must become adept with acute bedside management of encephalopathy, status epilepticus, and other life-threatening neurological conditions. This includes knowledge of current national guidelines (e.g., therapeutic hypothermia and brain monitoring) and expertise to adapt these to a specific center's resources. Trainees must also become proficient in neurological prognostication, including understanding the impact of neuroprotective therapies and developmental care and exposures to pain, infection, surgery, and critical illness. Finally, they must develop skills enabling effective communication with families. Specific recommendations include the following:

- A minimum of six months of direct care or consultation for inpatient neonates with neurological disorders who are admitted to the NICU to develop the skills and

TABLE 3.
Suggested Training Schedule

<p>Clinical pathway, 1 year</p> <ul style="list-style-type: none"> • Neonatal neurocritical care service, 6-8 months, depending on the trainee's residency experience • Outpatient clinics, 1-2 months (or minimum two half-days/month if concurrent with inpatient rotations) <ul style="list-style-type: none"> ○ Neonatal neurology clinic, 1-2 clinics/month ○ Fetal consults, includes participation in both inpatient and outpatient consults ○ Other clinics including high-risk infant follow-up, psychiatry, neuromuscular and cerebrovascular clinics, 1-2 clinics/month • Neuroradiology, 1 month • Electrophysiology, 1 month • Elective, 2-3 months (research and/or clinical rotations based upon trainee interests) <p>Research pathway, 2-3 years</p> <ul style="list-style-type: none"> • 1 year clinical pathway as above (elective rotations may be used for targeted research activities) • 1-2 years clinical, translational, or bench research • Coursework relevant to the research pathway, e.g., <ul style="list-style-type: none"> ○ Master's degree in clinical research or epidemiology ○ Master's degree in data science or bioinformatics
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expertise to direct neurological evaluation and management. (REQUIRED)

- If newborns with cardiac anomalies are cared for in a separate cardiac ICU (CICU), training should include at least one month providing neurology consultation for neonates in the CICU to achieve familiarity with the unique course and management of newborns with congenital heart disease with neurologic injury. (REQUIRED)

Outpatient training

The overarching goal of outpatient training is for the trainee to understand the long-term clinical course of neurological conditions that present in the fetal and neonatal periods. The trainee must become adept at diagnosing and providing initial evaluation and management for the developmental disabilities that arise subsequent to fetal-neonatal neurological conditions, including neuro-motor disabilities (e.g., cerebral palsy), epilepsy, cognitive dysfunction, autonomic dysfunction, cerebral visual impairment, and state regulation (e.g., sleep, mood). Trainees should become familiar with available equipment, therapies, and medical and surgical treatments for spasticity, cerebral palsy, and cerebral visual impairment. The trainee is also expected to gain valuable exposure to methods for prenatal evaluation of neurological disorders, develop familiarity in interpreting fetal MRI, be aware of available fetal surgical therapies and/or trials (e.g., *in utero* neural tube defect repair), and be familiar with local termination laws and counseling for fetal consults. Finally, the trainee should become familiar with local and regional resources available to the patient and their families such as early intervention services, state Medicaid programs, federal disability programs, and local pediatric hospice programs. Specific recommendations include the following:

- Outpatient rotation(s) in neonatal neurology clinics, as well as exposure to fetal neurology consults, infant development or high-risk follow-up clinics, and physiatry or rehabilitation clinics (and/or equipment, spina bifida, and spasticity clinics). Suggested exposure is one to two months (or minimum two half-days/month if concurrent with inpatient rotations). (REQUIRED)
- Elective rotations in EEG, neuroimaging, maternal-fetal medicine (including inpatient and outpatient fetal consults, fetal imaging, fetal cardiology, and fetal pathology), palliative care, and perinatal pathology (including fetal-pediatric autopsy and placental pathology), if available and depending upon the trainee's career goals. (SUGGESTED)

Didactic training

A formal, multidisciplinary education curriculum specific to fetal-neonatal neurology is mandatory. The trainee is expected to actively participate in conferences and lead fetal-neonatal neurology teaching sessions for medical students and resident physicians. Didactic conferences should include contributions from maternal-fetal medicine, neonatology, pediatric critical care,

neonatal nursing, neurology, neurosurgery, neuroradiology, neurophysiology, pathology, genetic/metabolic, palliative care, and neurorehabilitation (including developmental care) subspecialties. Specific recommendations include the following:

- Structured multidisciplinary educational program in fetal-neonatal neurology that includes didactic lectures, supplemented by journal clubs, morbidity and mortality rounds, and/or ethics conferences. See [Appendices 1 and 2](#) for expanded lists of relevant neonatal and fetal neurology topics to be considered for inclusion in didactic curricula. (REQUIRED)
- Bedside teaching rounds and/or case conferences that incorporate neurophysiology, neuroradiology, and fetal and placental pathology. (REQUIRED)
- Fellows shall also attend local conferences relevant to fetal-neonatal neurology, including neonatology, maternal-fetal medicine, neurology, genetics, pathology, and neuroimaging conferences.

Neurodiagnostic and neuroimaging tools requiring proficiency

Neurodiagnostic and neuroimaging tools are used in the neonatal neurocritical care setting to determine both diagnosis and prognosis and are a key component of patient management and discussions with families.¹⁻³ For both neurodiagnostic and neuroimaging tools, the neonatal neurologist must become proficient in the following as they apply to the term and preterm neonate:

- Indications and guidelines for performing monitoring and imaging studies¹⁷
- Interpretation of monitoring and imaging study results
- Management decisions based on monitoring and imaging study results
- Communication of study results to allied health professionals and parents

Neuroimaging

Cranial ultrasound

Cranial ultrasound (CUS) is the most commonly used imaging modality in the NICU.^{1,2} It is noninvasive and can be used readily at the bedside. Neonatal studies should routinely provide coronal, sagittal, and posterior fossa views of the brain. Cerebral blood flow and intracranial pressure can also be assessed using Doppler studies. CUS is used principally for screening examinations and serial assessments of cerebral injury in term and preterm infants, although it is limited in its ability to detect injury in specific brain regions.

Magnetic resonance imaging

MRI provides valuable information regarding cerebral development and acute and chronic brain injury not available from other imaging modalities.^{1,2,18} Magnetic resonance spectroscopy also enables assessment of brain injury and cerebral metabolism (i.e., for infants with suspected inborn errors of metabolism). Over the past decade, procedures to study term and preterm infants safely

without the use of sedating medications have become increasingly established. Growing numbers of studies have correlated neonatal neuroimaging results with neurodevelopmental outcomes in high-risk neonatal populations.

Trainees should spend at least one month during the training period reviewing CUS and MRI studies with board-certified pediatric radiologists and neuroradiologists experienced in the interpretation of neonatal studies. The trainee should become adept in identifying postmenstrual age-specific normal patterns, common patterns of injury (e.g., changes in diffusion-weighted and perfusion imaging in infants with stroke or hypoxic-ischemic injury), and/or developmental abnormality (e.g., malformations of cortical folding) and anticipated changes in patterns of abnormality with time across both modalities. As part of these activities, trainees should also gain exposure to interpretation of magnetic resonance spectroscopy and fetal MRI studies with concerns for central nervous system abnormalities. Finally, although not used routinely in the NICU, trainees must gain experience in interpretation of neonatal head computerized tomography studies as portable and/or standard studies may be performed to assist in clinical decision-making when access to other imaging modalities is limited because of critical illness. (REQUIRED)

Neurophysiological monitoring

Electroencephalogram

Continuous video EEG is the gold standard for detecting seizures in neonates.^{19,20} Brain monitoring using EEG and adapted montage amplitude-integrated EEG (aEEG) is used to assess degree of encephalopathy and the presence of seizures in neonates who are admitted to the neurocritical care unit.

Trainees should spend at least one month during the training period reviewing EEGs with a board-certified neurophysiologist who has experience with neonatal monitoring to become adept at determining background EEG pattern and seizures from artifact. Proficiency in aEEG training can be accomplished with frequent bedside practice and assistance from review articles and an aEEG atlas.²¹ (REQUIRED)

Optical near-infrared spectroscopy

Near-infrared spectroscopy (NIRS) is a noninvasive method for trending of brain tissue oxygenation. It is useful to guide hemodynamic management to optimize cerebral oxygenation in critically ill term and preterm neonates.^{22,23} Trainees should gain exposure to NIRS technology and interpretation of neonatal NIRS results. (REQUIRED)

Institutional programmatic requirements for fellowship training

Multiple programmatic requirements are necessary to establish and support a fetal-neonatal fellowship that provides comprehensive and balanced training that meets the needs and interests of individual candidates. Principal among these is a sufficiently broad clinical and research infrastructure to support well-rounded training at an academic center. In addition, there must be inpatient and outpatient care with adequate volume and variety of

neurological disorders to provide the trainee with education in congenital and acquired neurological disorders of the newborn. Finally, training should include exposure to and/or participation in research relevant to fetal-neonatal neurology, whether clinical, translational, or basic science. Specific recommendations include the following:

Inpatient

- Level III/IV NICU. (REQUIRED)
- An inpatient neonatal neurocritical care service that manages a broad range of preterm and term newborns with common and rare neurological disorders. (REQUIRED)
- Subspecialists with expertise in the diagnosis and management of newborns with congenital or acquired, central and peripheral neurological disorders of the fetus and newborn. This includes neurologists, neonatologists, neurophysiologists, neuroradiologists, neurosurgeons, perinatal pathologists, neuropathologists, and geneticists/metabolic specialists. (REQUIRED)
- Inpatient rounds closely integrated with the NICU team to form a comprehensive understanding of the medical issues primary or secondary to the neurological condition, discuss the priority of neurological plans, and convey a cohesive message to families. (REQUIRED)
- Inpatient neonatal neurocritical care rounds led by a child neurologist with at least 25% of clinical activities dedicated to fetal-neonatal neurology. (SUGGESTED)
- Readily available inpatient EEG monitoring and neuroimaging optimized for the newborn brain (as per neurodiagnostic and neuroimaging tools requiring proficiency section). (REQUIRED)
- Experts in palliative care and ethics to help address the unique difficulties of decision-making and care of newborns with severe congenital or acquired neurological disorders and/or complex medical problems that include neurological disorders. (REQUIRED)
- Rehabilitative services, including physical and occupational therapy, physiatry, and lactation support. (REQUIRED)
- A maternal-fetal medicine clinical service with expertise in providing care for fetuses with neurological concerns beginning antenatally and continuing through the time of delivery and immediate postnatal course. (REQUIRED)
- Specialized bedside nurses and/or nurse practitioners with expertise in neurological conditions in newborns. These individuals can be key members in training, together with social workers and care coordinators who assist families in navigating the health care system. (SUGGESTED)

Outpatient

- A multidisciplinary, longitudinal neonatal neurology outpatient clinic, which includes access to neuropsychologists, therapists, physiatrists, and nurses. (REQUIRED)
- A fetal neurology consult service with specialized fetal neuroimaging. (REQUIRED)

- Fetal cardiology, palliative care, and disease-specific neurology clinics, including psychiatry, equipment, spina bifida, and cerebral palsy clinics. (SUGGESTED)

Other

- An active research program in fetal-neonatal neurology. One-year fellowships will limit the types of projects that can be conducted, although exposure to and participation in research should be encouraged. A trainee pursuing a two- to three-year fellowship can complete a research project conducted largely by the trainee. (REQUIRED)
- Given the rapidly evolving nature of neonatal neurocritical care, trainees should become engaged in clinical protocol review and development and/or a quality improvement project. (REQUIRED)
- A format for evaluation of the trainees on an ongoing basis, as well as formally at least every six months (per current ACGME standards). Evaluations should incorporate feedback from multiple members of the inpatient and outpatient fetal-neonatal neurology teams (e.g., a 360-degree approach). (REQUIRED)
- A mechanism for trainees to evaluate the program (anonymously, which necessitates combining more than one trainee evaluations) with regard to the success of the program in producing well-trained graduates equipped to practice independently. (REQUIRED)

Conclusions

There is a growing need for pediatric neurologists and neonatologists with familiarity and specialty training in fetal-neonatal neurology. Concomitant with this increasing demand, the number of dedicated training opportunities in the field continues to expand, preparing graduates to join existing neonatal neurocritical programs and/or establish new programs with dedicated clinical and educational missions. This document provides an initial framework toward standardization of training environments in this field, providing guidance regarding requisite clinical and educational activities and programmatic requirements necessary to prepare trainees to independently provide expert care for neonates with neurological concerns in both inpatient and outpatient settings. The proposed model has the potential to produce recognized standards of professional excellence for training, including a pathway toward ACGME certification for graduates. With consistent implementation, the result will be improved collaboration and learning across neonatal neurocritical care programs, leading to growth and innovation in clinical and research environments, improved visibility for the field, and, most importantly, continued improvements in care for NICU patients.

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Appendix 1. Neonatal neurology topics to be considered for incorporation into didactic curricula

Neurodiagnostic Tools

1. Neurologic exam—normal newborn; Apgar score; Sarnat score
2. EEG
3. aEEG; aEEG versus EEG
4. EEG trend algorithms
5. Evoked studies—brainstem auditory evoked response (BAER); visual evoked potential (VEP); somatosensory evoked potential (SSEP)
6. Cranial ultrasound and Doppler
7. CT scans—portable; standard
8. Anatomical MRI—T1; T2; diffusion-weighted image (DWI)
9. Advanced MRI—diffusion tensor image (DTI); functional connectivity MRI (fcMRI); magnetic resonance spectroscopy (MRS); perfusion
10. Near-infrared spectroscopy (NIRS)
11. Placental pathologies
12. Autopsies

Brain Development

1. Normal neuroembryology
2. Developmental neurobiology
3. Myelination
4. Brain malformations—Dandy–Walker malformations; encephalocele; agenesis of the corpus callosum
5. Spine malformations—neural tube defects
6. Migrational disorders—lissencephaly; pachygyria; schizencephaly, heterotopias
7. Hindbrain malformations

Development

1. Developmental assessments (age, visual, motor, social, IQ, pros and cons)
2. Prechtl and fidgety movements
3. Outcome measures—NICU Network Neurobehavioral Score (NNNS); Dubowitz score; Gross Motor Function Classification System (GMFCS); Alberta Infant Motor Scale (AIMS); Bayley III
4. Outcomes of preterm infants
5. Outcomes of hypoxic-ischemic encephalopathy (HIE)
6. Outcomes of cerebral palsy

Neonatal Seizures and Epilepsy

1. Etiology of neonatal seizures
2. Neonatal seizure evaluation and workup
3. Neuromonitoring
4. Neonatal seizure therapies—anticonvulsant medications; lidocaine
5. Neonatal onset epilepsies
6. Risk for postnatal epilepsy

Neonatal Brain Injuries

1. Trauma—extradural hemorrhage; subdural hemorrhage; subgaleal bleeds, skull fractures
2. Premature infants—intraventricular hemorrhage (IVH); periventricular leukomalacia; ventriculitis; posthemorrhagic ventricular dilatation
3. Term infants—HIE/neonatal encephalopathy; intracranial hemorrhage; IVH; infections (TORCH, etc.)

Neurogenetics

1. Chromosomal and genetic disorders
2. Neurocutaneous disorders
3. Inborn errors of metabolism with neonatal presentations
4. Leukodystrophies
5. Mitochondrial disorders
6. Catastrophic neurodegenerative disorders of fetal or neonatal onset

Neuromuscular

1. Neonatal hypotonia
2. Arthrogryposis
3. Common neonatal neuromuscular disorders
4. Critical illness myopathy
5. Neurodiagnostic tools

Neuroprotection

1. Neurosupportive care
2. Therapeutic hypothermia
3. Erythropoietin
4. Clinical trials—xenon; cord stem cells; mucomyst
5. Seizure monitoring and treatment

Fetal, Perinatal and Neonatal Strokes

1. Incidence; causes
2. Neurodiagnostic evaluation
3. Protocols
4. Outcomes

End of Life Issues

1. Brain death
2. Futile or palliative care
3. Autopsies

Outcomes and Disabilities

1. Developmental delay
2. Cortical visual impairment
3. Cerebral palsy
4. Intellectual disabilities—attention deficit hyperactivity disorder; learning disabilities; mental retardation

Therapies and Rehabilitation

1. Feeding
2. Visual therapy
3. Physical and Occupational Therapy
4. Speech therapy
5. Treatments for spasticity—baclofen; botox and phenol injections; tendon release
6. Communication devices
7. Equipment—bath chairs; standers; activity chairs; ankle-foot orthoses (AFOs); wheelchairs; walkers; gait trainers

Other

1. Neonatal abstinence syndrome
2. Meconium aspiration syndrome/pulmonary hypertension
3. Congenital diaphragmatic hernia
4. Necrotizing enterocolitis
5. Hydrops fetalis
6. Gastroschisis/omphalocele/tracheoesophageal fistula
7. Hyperbilirubinemia
8. Hypo/hyperglycemia

9. Brachial plexus injury
10. Pain management and analgesic exposure/use
11. Anesthetic exposure/use
12. *In utero* exposure to drugs of abuse
13. *In utero* exposure to selective serotonin reuptake inhibitors (SSRIs) and other neuropsychiatric medications
14. Maternal mental health
15. Epidemiology and public health

Appendix 2. Fetal neurology topics to be considered for incorporation into didactic curricula

Fertility Issues and Testing

1. *In vitro* fertilization/intrauterine insemination
2. Preimplantation genetic diagnosis

Prenatal Screening

1. Maternal serum screening
2. First-trimester screening
3. Cell-free DNA/noninvasive prenatal testing (NIPT)
4. Neonatal Autoimmune Thrombocytopenia (NAIT) testing
5. TORCH testing
6. Carrier testing
7. Thrombophilias
8. Chorionic villus sampling (CVS) and amniocentesis
9. Fetal ultrasound and Doppler
10. Fetal MRIs
11. Fetal magnetoencephalogram (MEG)
12. Autopsies

Placenta

1. Anatomy and function
2. Biomarkers
3. Ultrasound—location; Doppler
4. MR imaging
5. Pathology—normal
6. Pathology—subchorionic hemorrhages; prematurity

Growth Issues

1. IUGR versus SGA versus asymmetric growth
2. Normative growth curves—biparietal diameter (BPD); head circumference; brain volumes
3. Microcephaly—2SD versus 3SD
4. Oligo- versus polyhydramnios
5. Cerebral blood flow and metabolism
6. Fetal circulation and brain development

Development

1. Prechtl movements
2. Swallowing

Maternal Conditions

1. Hypothyroidism
2. Mood disorders and SSRIs
3. Epilepsy and antiepileptic drugs
4. Multiple sclerosis

CNS Development

1. Neuroembryology
2. Developmental neurobiology

3. Gyration development
4. Cerebellar and vermian development
5. Myelination

Common Chromosomal and Genetic Syndromes

1. Trisomies—21; 13; 18
2. Microarray abnormalities
3. Tuberous sclerosis
4. Dystroglycanopathies
5. Neurocutaneous melanosis

CNS Maldevelopment

1. Cerebrum—anecephaly; holoprosencephaly; schizencephaly; focal versus diffuse polymicrogyria; pachygyria; lissencephaly; transcortical or subependymal heterotopias; hemimegalencephaly
2. Corpus callosum—dysgenesis or complete agenesis; associated conditions
3. Septum pellucidum—cavum septum pellucidum; cavum vergae; cavum velum interpositum; associated conditions
4. Posterior fossa—mega cisterna magna; Blake pouch cyst; arachnoid cysts; occipital encephalocele; Dandy–Walker malformation
5. Brainstem—congenital muscular dystrophies; Joubert syndrome; pontotegmental dysplasia; pontocerebellar hypoplasia; brainstem disconnection syndrome
6. Cerebellum and vermis—vermian hypoplasia; cerebellar dysplasia; rhomboencephalosynapsis
7. Cranium—encephalocele
8. Spine—neural tube defects

Ventriculomegaly

1. Idiopathic
2. Cerebral malformation
3. Obstructive hydrocephalus

Vascular

1. Intraventricular hemorrhages
2. Intraparenchymal hemorrhages
3. Extracranial hemorrhages
4. Ischemic strokes
5. Vascular malformations

Infections

1. TORCH (toxoplasmosis; rubella; cytomegalovirus [CMV]; herpes simplex virus [HSV])
2. Lymphocytic choriomeningitis virus (LCMV)
3. HIV
4. Zika virus
5. Parechovirus
6. Parvovirus

Neuromuscular

1. Clubfoot
2. Arthrogryposis

Early-Onset Neurodegenerative Disorders

1. Inborn errors of metabolism (IEM)—nonketotic hyperglycinemia (NKH); sulfite oxidase deficiency; glutaric aciduria type 1; Smith-Lemli-Optiz
2. Mitochondrial disorders—pyruvate dehydrogenase deficiency; pyridoxal-5-phosphate deficiency; Leigh syndrome; pontocerebellar hypoplasia
3. Leukodystrophies—Zellweger; Aicardi Goutieres

Brain Tumors

1. Tuberous sclerosis
2. Neurocutaneous melanosis
3. Germ cell tumors—teratoma

Fetal Seizures

1. Early infantile epileptic encephalopathies—NKH; ARX; channelopathies; pontocerebellar hypoplasia

End of Life Issues

1. Stillbirths
2. Termination—state and federal laws; induction versus extraction
3. Postnatal counseling and planning
4. Recurrence risk counseling

5. Comfort or palliative care**6. Autopsies and genetic testing****Outcomes and Disabilities**

1. Immediate postnatal issues
2. Short-term issues
3. Long-term issues

Therapies

1. Fetal infections—HIV; CMV; Toxoplasmosis
2. Autoimmune—NAIT
3. Fetal surgery—myelomeningocele; tracheoesophageal fistula; congenital diaphragmatic hernia
4. Vascular—arteriovenous malformations; lymphatic malformations