1 Pediatric Neuroanesthesia: Evolution of a New Subspeciality

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Key Points

- Modern neurosurgery and neuroanesthesia have existed and developed concurrently, largely due to significant contributions by pioneers to both specialties.
- Rapidly evolving diagnostic and surgical modalities have facilitated the possibility of safe and effective complex neurosurgeries in children.
- The development of pediatric neuroanesthesia as a separate subspecialty is essential considering the unique anatomical and physiological features, the requirement of special skill sets and experience with invasive procedures, and effective management of the child in the perioperative period.
- Currently, the setting up of advanced training programs in pediatric neuroanesthesia and neurointensive care is in its nascent stage.
- Future prospects in the field of pediatric neuroanesthesia include meaningful research in the management of significant comorbid neurological diseases, including cerebral palsy, epilepsy, and traumatic brain injury.

1.1 Introduction

A better understanding of human pathophysiology as well as technological advances has encouraged every specialty of medical science to focus on specialized care instead of generalized approaches. During the last 100 years, a lot of development has been witnessed in the anesthesia practice as a specialty of medicine. Several subspecialties have come up intending to approach a particular set of patients to ensure better care and provide clinical scientists with research opportunities. Cardiac anesthesia, neuroanesthesia, obstetric anesthesia, pediatric anesthesia, pain medicine, palliative care, and critical care medicine are well-established, currently, with a distinct identity.

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1.2 Development of Neuroanesthesia Along with Neurosurgery

Neuroanesthesia, as a specialty, should be discussed in the context of the evolution of neurosurgery. Although trephination or trepanning used to be carried out during the primitive civilizational period and continued until the early twentieth century [1] for different beliefs, the beginning of neurosurgery and neuroanesthesia must be viewed from the late part of the eighteenth and early nineteenth centuries [2]. The significant discoveries of anesthesia during the nineteenth century gave shape to the development of modern neurosurgery. Carbon dioxide, hydrogen, and nitrogen were discovered during the end of the eighteenth century; their role in anesthesia was explored, along with other agents such as oxygen and nitrous oxide [3]. Sir Humphry Davy (1798) suggested that the use of nitrous oxide (laughing gas) could relieve pain during surgery, and it was used quite often in dental extraction procedures for analgesia. However, its popularity was reduced with ether's introduction to remove a neck tumor by Dr. Crawford Long in 1842 [2]; unfortunately, it remained unpublished until 1849 [4]. After the first successful public demonstration of ether use at Massachusetts General Hospital by William Thomas Green Morton on 16 October 1846, there was a quick spread of news worldwide, and it led to a revolution in the field of surgery and anesthesia. Subsequently, Sir James Young Simpson introduced chloroform (1847) which further overshadowed nitrous oxide. While chloroform was mainly used in Europe and South America, ether was used in England and North America [2]. Therefore, the use of chloroform and ether became routine for modern anesthesia. However, the implementation of anesthetics in neurosurgery took a decade to develop [3]. The pioneer neurosurgeons then stepped in and utilized these agents for brain surgery to establish the specialty of neurosurgery. The contributions of Sir William Macewen (1848–1924; Glasgow), a precursory neurosurgeon and pioneer anesthetist, marked the dawn of neuroanesthesia; he was a general surgeon with interest in neurosurgery. In 1879, he performed the first-ever successful brain tumor removal at the Glasgow Royal Infirmary. The procedure was carried out under endotracheal anesthesia and not with a tracheotomy which was the convention till then [2]. He developed metallic tubes which could be introduced into the trachea and, later on, the red rubber tubes. A decade later, Sir Ivan Magill and Stanley Rowbotham popularized the technique of endotracheal anesthesia, which is still in use in the current-day practice [5]. Victor Horsley, a contemporary of Macewen and a general surgeon with a special interest in neurosurgery, carried out animal experiments and investigated the effects of ether, chloroform, and morphine on intracranial contents. He recommended using chloroform rather than ether; although relatively safe, ether caused an increase in blood pressure and, hence, is considered to have a potential for hemorrhage. He described anesthesia for brain surgery in *British Medical Journal* in 1888. The use of morphine was excluded from his anesthesia regimen due to its respiratory depressant effects. Because of his interest in anesthesia, he became part of the "Special Chloroform Committee," which recommended that the use of chloroform in a concentration of more than 2% was unsafe. Horsley believed a dose of less than 0.5% after bone removal during the craniotomy is safe [6]. He also described the role of local anesthesia in the form of cocaine infiltration over the dura, especially in patients with cardiac dysfunction, where chloroform is contraindicated [7]. An interesting fact about the early days of neurosurgery is the time taken for the procedures, which is described in the literature as lasting up to 1.5 h (usually 30 min!) which reduced the anesthetic needs. This was mentioned by Dr. Zebulon Mennell, the first British neuroanesthetist (who worked with Victor Horsley), that an ambidextrous Horsley seldom took more than half an hour for his cranial cases [8]. Compare this to modern-day neurosurgery practice with advanced operating techniques that have prolonged the procedure's duration and require ever-modifying anesthetic needs.

Harvey Cushing, another contemporary pioneer of neurosurgery and anesthetics, suggested using ether anesthesia while restricting chloroform use in children. He was the first to introduce the concept of induction of anesthesia [3].

His initial anesthesia experience as a medical student was terrible. He was a stand-in anesthetist, and the patient died of aspiration of vomitus. Along with Codman, he utilized his experiences to develop an anesthesia record (ether record). He recommended continuous monitoring of pulse rate, respiration, and temperature every 5 min. He later added blood pressure charting after a visit to Italy (1900), where he was introduced to Riva-Rocci cuffs [9]. Due credit must be given to Cushing to realize the need for a full-time anesthetist, and he employed Dr. Griffith Davis, with whom he reported performing over 300 cranial surgeries. He mentions that an expert and fully devoted anesthetist is essential in neurosurgeries to deal with major issues like the positioning of the patient, level of narcosis, and continuous monitoring of cardiac and respiratory rhythm by auscultation [10].

Deliberate hypotension was described in neurosurgery by Fedor Krause (1857–1937), a German neurosurgeon. He used increasing concentrations of chloroform to cause hypotension and, hence, reduce bleeding. Induced hypotension using non-anesthetic drugs was described by Janice Peeler in Australia for the first time in scoliosis correction surgeries (Harrington rods) using sodium nitroprusside for reducing bleeding [11]. Krause also introduced the surgical treatment of epilepsy in Germany and was an early practitioner of the intraoperative electrostimulation of the cerebral cortex. He also emphasized the importance of a light plane of anesthesia during brain surgery as the brain was insensitive to pain [7].

The contributions of Albert Faulconer (Mayo Clinic) through publications on the electroencephalogram (EEG) responses to anesthetics and the development of an EEG-based device to monitor the anesthetic depth (1949) are considered significant to the beginning of modern neuroanesthesiology [12, 13]. This was later (1969) followed by further such demonstrations by John D. Michenfelder, which were majorly responsible for the spread of Neuroanesthesia as a sub-specialty. It is for this reason that Michenfelder is considered the Father of Modern Neuroanesthesiology [14, 15]. Robert J. White, the first neurosurgeon to perform a successful "cephalic exchange" in monkeys (1971), is also credited with a significant contribution to neuroanesthesia. Teaming up with Maurice S. Albin, a neuroanesthesiologist, he conducted significant research on hypothermia for neuroprotection after spinal cord injury. He demonstrated total hemispherectomy in monkeys and paved the way for the procedure to be adapted for the treatment of intractable epilepsy and resection of large tumors in humans [16, 17]. Our understanding of intracranial dynamics is based on two significant contributions in the form of Monro-Kellie doctrine, which explains the relationship between the components of the intracranial compartment and the description of intracranial pressure (ICP) waveforms by Lundberg [18–20]. These two basic principles still influence neuroanesthesia and intensive care practice, and to date, research is on to identify the ideal intracranial dynamics using various monitoring modalities. This is even more significant in children as the cerebral hemodynamics are fluctuating with increasing age.

Many important landmarks in anesthesia were achieved by people who did pioneering work in neurosurgery, thanks to their continued efforts in striving for the best possible care of their patients. Their work was greatly enabled by the discovery of the germ theory of disease and the advent of the concept of aseptic precautions. Apart from their innovations in surgical procedures and their meticulous techniques, these pioneers also contributed immensely to anesthesia by describing different anesthetic agents used, their administration techniques, and monitoring these patients. Because of due realization, dedicated anesthesiologists were appointed for intraoperative care, resulting in a much better understanding of neurophysiological requirements during surgery.

1.3 Development of Pediatric Neurosurgery as a Subspecialty

Surgery of the brain and spinal cord among children constitutes a significant proportion of neurosurgical procedures. Starting from prehistoric times until the Harvey Cushing era, neurosurgery was sporadically practiced on children. Pediatric neurosurgery, as a subspecialty, was in a developing stage when the pioneering neurosurgeons such as Harvey Cushing, Walter Dandy, Norman Dott, and Kenneth McKenzie operated in various countries on children with hydrocephalus or brain tumors. However, the formal development and teaching of the specialty were started by *Franc Ingraham* under the directions of Harvey Cushing (***father of neurosurgery***) at the Boston Children's Hospital when he established the first center for treatment of neurosurgical diseases in children. By the early 1950s, the role of pediatric neurosurgery was already being defined in the major cities worldwide, Boston, Chicago, London, Paris, and Toronto, to name a few. Ingraham is credited with describing methods for the treatment of conditions like craniosynostosis, diastematomyelia, hydrocephalus, spina bifida, and subdural hematomas. He is credited with the training of many surgeons in pediatric neurosurgery and, hence, is also considered the ***father of pediatric neurosurgery*** [21]. Ingraham and his protégé, Donald Matson, published *Neurosurgery of Infancy and Childhood* in 1954, the first textbook on pediatric neurosurgery. Matson was a brilliant technical surgeon and used to resect craniopharyngiomas before the introduction of surgical microscopes [22].

The notable contributions of Cushing in pediatric neurosurgery include the description of a lumbo-peritoneal shunt and an article highlighting his experiences in the management of cerebellar astrocytomas [23]. Hydrocephalus is a condition associated more commonly with the pediatric population and several innovations for the drainage of cerebrospinal fluid (CSF) starting from Cushing's lumbo-peritoneal shunt to Torkildsen (1939) describing a ventriculocisternal shunt and Matson's lumbo-ureteral (1949) and ventriculo-ureteral (1951) shunts. Valve-based shunts were first described by Holter, which led to the first reported CSF drainage into the jugular vein in 1952 [24, 25]. Since then, numerous improvements have been made in the materials and techniques used, including endoscopy and image guidance.

The first instance of the description of epilepsy surgery was by Horsley (1886) of a 22-year-old man who had been suffering from seizures since 15 years of age. A craniotomy was performed for the removal of a focus of irritation (proposed by Jackson in 1870) [26].

Craniectomy for craniosynostosis was first described in a 9-month-old infant by Lane in 1892. He mentions the use of ACE (alcohol, chloroform, and ether) mixture for anesthesia. Ironically, the child died 14 h postoperatively, and the cause of death was attributed to the effect of anesthesia [27, 28].

Moyamoya disease was first recognized in 1957 in Japan by Takeuchi and Shimizu, and the characteristic angiographic appearance of a "puff of smoke" was described by Takaku in 1969. The earliest described surgery for moyamoya disease was cervical carotid sympathectomy and superior cervical perivascular ganglionectomy by Suzuki [29, 30].

The first edition of the *Guidelines for the Acute Medical Management of Severe Traumatic Brain Injury in Infants, Children, and Adolescents* was published in 2003 [31]. Although the entity was recognized much earlier, significant research went into developing these guidelines by the *Brain Trauma Foundation*, which is being updated periodically. The first pediatric neurosurgical society, the European Society for Pediatric Neurosurgery (ESPN), was founded when the first such scientific meeting was held in Vienna, Austria, in 1967 [21]. In 1971, Jacques Rougerie held a meeting in Paris just before the second meeting of ESPN; it was decided to found an international society which was formally established in the subsequent year (1972) as the International Society for Pediatric Neurosurgery (ISPN). During the second meeting of ISPN, the creation of their official journal 'Child's Brain' was announced, which was later rechristened (1985) as 'Child's Nervous System.' The American Society of Pediatric Neurosurgeons (ASPN) was formed in 1978; similar professional bodies were formed in Japan (1973), Mexico (1999), and Australia (2002).

Training in pediatric neurosurgery is addressed with fellowship programs all over the world. To begin with, in 1953, there was a so-called fellowship at Boston Children's Hospital, with "supernumerary residency." By 1978 the programs were sustained at five places: Boston, Toronto, Philadelphia, Chicago, and Los Angeles [32]. Currently, many places offer such fellowships. A 1-year clinical fellowship following the completion of a general neurosurgical residency is usually recommended [21, 33]. There is a paucity of such advanced training to meet the growing disease burden in low- and middle-income countries (LMIC). Expertise in the management of hydrocephalus and spina bifida, the two of the most common pediatric neurosurgical conditions, offers better outcomes in terms of reduced morbidity and mortality. The CURE Hydrocephalus and Spina Bifida (CHSB) fellowship offers advanced subspecialty training to equip surgeons from LMIC with optimum surgical skills and equipment to manage effectively such common childhood neurosurgical conditions [34]. All India Institute of Medical Sciences (AIIMS), New Delhi, and Park Clinic, Kolkata in India, offer pediatric neurosurgery fellowships. A repository of information concerning pediatric neurosurgery fellowships worldwide is available on the ISPN website (https://www.ispneurosurgery.org/international-fellowships/).

1.3.1 Neurosurgery: *An Indian Perspective*

Although Dr. Ram Ginde's survey of neurosurgery in India between 1926 and 1953 gives an idea of what was then being done at most large teaching hospitals in the country, it is well known that prior to 1949, neurosurgery was being practiced by general surgeons [35]. Meanwhile, Professor Jacob Chandy of Christian Medical College (CMC), Vellore, received his neurosurgical training at the Montreal Neurological Institute (MNI) with Wilder Penfield and in Chicago with Theodore Rasmussen [36]. It can be said that his return to CMC marked the beginning of modern neurosurgery in India. Chandy established the first neurosurgery department in South Asia at CMC and initiated the neurosurgical training and neurological services in 1957–1958. Several of his trainees pioneered neurosurgical departments all over India. He was one of the four founder members of the Neurological Society of India (NSI) in 1951 and was also the founder president (1952) [36, 37]. His tremendous contributions place him as the ***father of neurosciences/neurosurgery in India***. Meanwhile, B. Ramamurthi, another pioneer neurosurgeon, after his training under Rowbotham of Newcastle, UK, started the Department of Neurosurgery in the Government General Hospital, Madras, in 1950 (Madras Institute of Neurology, MIN); V. Rajagopalan underwent training in neuroanesthesia in the UK and joined MIN in 1953 [38].

Significant contributions to neurosurgical literature from India were in the 1960s when Wadia described his pioneering work on congenital atlantoaxial dislocations [39]. Subsequently, P N Tandon, a pioneering neurosurgeon, an MNI alumnus, and founder of the Department of Neurosurgery at AIIMS, New Delhi, published a series of 30 cases of anterior encephalocele in children [40]. Upadhyay, a pediatric surgeon, created an indigenous shunt for hydrocephalic children [41]. The development of modern pediatric neurosurgery in India began with holding the 17th Annual Conference of ISPN at Mumbai (1989). Dr. S. N. Bhagwati of Bombay Hospital hosted a satellite meeting of the International Society for Pediatric Neurosurgery (ISPN) in Mumbai just before the World Congress [42]. Enthused with the success of the meeting, he formed a special interest group (SIG) on pediatric neurosurgery in India, which was later formalized as the Indian Society for Pediatric Neurosurgery (IndSPN) in 1990 with himself as the founder president. He became the President of the International Society for Pediatric Neurosurgery (ISPN) in 1994–1995, being the first Indian to be nominated to that position. IndSPN is responsible for organizing regular meetings and continuing medical education (CME) programs in cooperation with the ISPN. Bhagwati was supported by a group of dedicated neurosurgeons from different parts of India. Notable among them are A. K. Banerji of AIIMS, New Delhi, a pioneer neurosurgeon of Northern India; S. Kalyanaraman; V. K. Kak; D. K. Chhabra of King George's Medical College, Lucknow; Chandrasekhar Deopujari of Bombay Hospital; and Ashok Kumar Mahapatra of AIIMS, New Delhi; they all succeeded him as presidents of IndSPN [43]. Among them, Prof. Mahapatra continued to work as a dedicated pediatric neurosurgeon throughout his career and contributed several scientific publications on pediatric neurosurgery, apart from editing two books—*Tenets of Craniosynostosis* and *Split Cord Malformations*. He was instrumental in carrying out the rare yet first successful craniopagus separation surgery in India (2017). The *Journal of Pediatric Neurosciences*, the official publication of the IndSPN, was launched in 2006 and continues to excel as an international journal on pediatric neurosurgery.

1.4 Pediatric Neuroanesthesia: *Not Just "Anesthesia" or "Neuroanesthesia"*

Pediatric neuroanesthesia is an evolving subspecialty in anesthesia that deals with the perioperative care of children during neurosurgery. As of now, pediatric neurosurgery is a well-established neurosurgical specialty to deal with the special challenges and considerations that a child with central nervous system (CNS) disease poses. Concurrently, the need for well-trained and skilled pediatric neuroanesthesiologists has also risen in recent times, focusing on dedicated care of such children. Pediatric neuroanesthesia owes most of its routines, techniques, and instrumentation to anesthetics for children in general. Perioperative anesthetic care of children requires catering to and adapting to the differences in children's anatomy and physiology from adults. Performing invasive maneuvers and procedures like dealing with airway, vascular cannulation, and positioning for surgery is always a challenge for the anesthesiologist. The response of neonates and infants to stress (bradycardia) is markedly different from older children and adults; they have poor metabolic control and are more prone to hypothermia. Combined with the general physiological differences, the neuroanesthesiologists have a better understanding of the neurological pathology and concerns relating to ICP; they play a major role in the optimal management of such children, greatly influencing the outcome.

Certain neurological conditions are specific to children, which can be attributed in part to their association with genetic abnormalities. Several syndromes with CNS and multi-system manifestations have been described, and the attending anesthesiologist needs to be aware of the problem at hand. Intracranial tumors, intractable epilepsy syndromes, craniofacial abnormalities (craniosynostosis and craniopagus twins), neurotrauma, hydrocephalus, spinal and cranial dysraphisms (neural tube defects), craniovertebral junction abnormalities (Chiari malformations), neurovascular diseases, moyamoya disease, the vein of Galen aneurysmal malformations, and kyphoscoliosis are some of the pathological conditions the anesthesiologist needs to have a thorough understanding of.

The perioperative anesthetic and neuro-intensive care management of pediatric traumatic brain injury is also significantly unique and is still a research topic. Although not restricted to pediatric neuroanesthesia specialty, research on the toxicity of anesthetic drugs on the developing brain could be a significant game-changer for the evolution of this specialty. The earliest descriptions regarding fetal neurosurgical diseases were from Charpentier (1887), who described fetal hydrocephalus in 200 cases, one of the major causes of maternal deaths [44]. The first description of a fetal neurosurgical procedure was by Barke et al. (1966), who described the use of gas ventriculography to confirm the diagnosis of hydrocephalus [45]. Cephalocentesis and ventriculo-amniotic shunting were followed in the 1980s [46, 47]. The first in utero endoscopic repair of neural tube defects (meningomyelocele) was done in 1994, which was deemed unsatisfactory and replaced by hysterotomy [48, 49]. Advancements in fetal neurosurgery started to begin after observing that open fetal MMC repair resulted in the reversal of Chiari II malformation [50]. Prospective studies have established superior outcomes with the prenatal treatment of hydrocephalus and neural tube defects [51].

The most common abnormality of intracranial circulation in children is arteriovenous malformation (AVM). Their high risk of intracranial hemorrhage mandates early management. Several advancements have been made in the treatment options ranging from open surgeries to endovascular techniques [52].

The performance of pediatric awake craniotomy is precluded by patient cooperation. Though neurosurgeries were performed even much before the pre-anesthetic era, Pasquet described the first awake craniotomy with combined local and general anesthesia [53]. In children, awake brain surgeries have been carried out for epilepsy and tumors in the eloquent cortex.

Deep brain stimulation (DBS), traditionally for the management of Parkinson's disease, has also been used to treat generalized dystonias [54]. In children, pallidotomy has been a surgical management option since the 1960s but with limited long-term efficacy data [55]. Deep brain stimulation for dystonia in an 8-year-old child was first described in 1996, with lasting efficacy noted at 20 years. Since then, several such surgeries have been carried out [56, 57].

Management of TBI in children has special considerations due to the neurophysiological differences (cerebral autoregulation) and differences in patterns of injury. Data pertaining to this topic is available since the early part of this century and evolving continuously [58–60]. Anesthetic neurotoxicity is one of the most intriguing topics of research in the conduct of pediatric surgeries, and certain features like longer duration of exposure and the prospect of multiple exposures with regards to neurosurgeries give more relevance to its consideration in the field of pediatric neuroanesthesia. Michenfelder is credited with early reports of nitrous oxide toxicity during anesthesia exposure in children [61]. Since then, literature is being updated periodically on this topic and has been covered in this textbook elsewhere. Although neuroanesthesiologists or pediatric anesthesiologists have been attending to pediatric neurosurgeries routinely in their practice by virtue of their clinical experience and advanced exposure, it is wise to believe that full-time pediatric neuroanesthesiologists, as a separate group, will create new dimensions to the perioperative and intensive care management of such children. This optimism is similar to the recommendation of the "Children's Surgical Forum," which views the children's welfare could be better served by a degree of sub-specialization [62]. The surgeries are recommended to be undertaken by appropriately trained designated surgeons with a workload sufficient to maintain competence. The task force for the Society of British Neurological Surgeons (SBNS) in 1998 defined the "Safe Pediatric Neurosurgery" objectives to ensure children's care to be of the highest quality and delivered by recognized pediatric neurosurgeons supported by staffs and facilities [63]. However, structured training programs on pediatric neuroanesthesia similar to pediatric neurosurgery are rare. In most places, pediatric anesthesiologists with exposure to neuroanesthesia manage the perioperative care of such patients. However, with increasing fellowship programs on neuroanesthesia, more neuroanesthesiologists with pediatric anesthesia experience manage the care. Cincinnati Children's Hospital Medical Center, USA, offers advanced pediatric neuroanesthesia fellowship (18 months' duration) for internationally trained candidates under the core fellowship program of pediatric anesthesia. In other universities of the USA, the experience of pediatric neurosurgical procedures for the neurosurgical anesthesia fellowship is offered as a part of rotational policy in conjunction with pediatric anesthesiology, which is the case in most parts of the world as well. In the Indian subcontinent, neuroanesthesiologists with advanced pediatric neurosurgery experience are the foremost practitioners of pediatric neuroanesthesia.

Specific literature in relation to pediatric neuroanesthesia was first published during the late 1960s and 1970s [64–70]. During the fifth Italian-French meeting on neuroanesthesia and resuscitation, a symposium on pediatric anesthesia was organized at Turin, Italy, probably for the first time [71]. The necessary presence of a skilled neuroanesthesiologist familiar with the physiologic and psychological needs of the children undergoing epilepsy surgery was highlighted for the first time [39]. Sulpicio Soriano and colleagues from Boston Children's Hospital continued emphasizing the role of pediatric neuroanesthesiologists for children undergoing neurosurgery in different scientific meetings and publications [72–75]. There is increased awareness of this specialty which has been reflected in terms of further publications during the last 20 years, and more such publications were added to the literature with a special issue on pediatric neuroanesthesia in the journal *Pediatric Anesthesia* [76–79].

The first textbook on Neuroanesthesia was published in 1964 by Andrew Hunter, Manchester [80]. James Edward Cottrell, the founder-editor of JNA, is credited with being the author of immensely popular textbooks in neuroanesthesia, from 'Anesthesia and Neurosurgery' (1980) [81] until the recent edition of 'Neuroanesthesia' (Cottrell and Patel) (2016) with a reasonably informative chapter on pediatric neuroanesthesia [82]. The JNA is affiliated with the Society of Neuroscience in Anesthesiology and Critical Care (SNACC). The formation of an organizational structure for neuroanesthesia began with the Neuroanesthesia Travelling Club of Great Britain and Ireland (1965), co-founded by Allan Brown and Andrew Hunter. The precursor for SNACC, the Neurosurgical Anesthesia Society (NAS) was formed in 1973 with John Michenfelder as its first president. The NAS has undergone title changes such as the Society of Neurosurgical Anesthesia and Neurological Supportive Care (SNANSC) in 1973 to the Society of Neurosurgical Anesthesiology and Critical Care in 1986, and a revised nomenclature of Society of Neuroscience in Anesthesiology and Critical Care, since 2009 [83].

In India, perioperative care for pediatric neurosurgery was provided by pediatric anesthetists, to begin with. After training in neuroanesthesia started at different institutions, it became a routine for trained neuroanesthesiologists to be involved in these children's care. Prof. SS Saini was the first designated faculty (assistant professor, 1979) of neuroanesthesia in India and became professor in 1987. He founded a dedicated Department of Neuroanesthesia at Neurosciences Center of AIIMS, New Delhi (1986–1987), and was supported by his mentees and colleagues, Harihar Dash and Parmod Bithal. Dash took over the departmental reins from Saini and, in 2001, registered the *Indian Society of Neuroanaesthesiology and Critical Care* as its founder president. In the subsequent year (2002), he initiated the first structured neuroanesthesia doctorate training program (3-year DM in Neuroanaesthesiology) in Asia/India; it included advanced pediatric neuroanesthesia. It was followed by several other institutions such as Sree Chitra Tirunal Institute for Medical Sciences and Technology (SCTIMST), Trivandrum; the National Institute of Mental Health and Neurosciences (NIMHANS), Bangalore; Post Graduate Institute of Medical Education & Research (PGIMER), Chandigarh; Jawaharlal Institute of Postgraduate Medical Education and Research (JIPMER), Puducherry; CMC, Vellore; and AIIMS-like institutions initiating the DM courses. It is probably the reason why most of the neuroanesthesia- or pediatric neuroanesthesia-related scientific articles from India are published after 2002. The practice of pediatric neuroanesthesia, however, is not restricted to these hospitals. The training continued to be provided earlier by renowned neuroanesthesiologists such as G. Parameswara and GS Umamaheswara Rao (NIMHANS, Bangalore), Grace Korula (CMC, Vellore), V Padmanabha Iyer and Annapurna Rout (SCTIMST, Trivandrum), Amna Goswami and Bibhukalyani Das (Bangur Institute of Neurosciences, Kolkata), and Vinod Grover (PGIMER, Chandigarh), to name a few. Mumbai neuroanesthesiologists also played an active role in this regard; prominent were Vasumathi Divekar (KEM Hospital) and Vikram Datar (Bombay Hospital).

1.5 Future Prospects as a Subspeciality

Neurosurgery as a specialty is rapidly evolving with the advent of newer diagnostic modalities such as functional magnetic resonance imaging (*f*MRI); surgical techniques, microneurosurgery, endoscopy, and stereotactic and robotic surgeries; and endovascular techniques. Many of these techniques are being increasingly employed in pediatric neurosurgery as well. It is essential that the neuroanesthesiologist or pediatric anesthesiologists need to be abreast of the latest developments to provide appropriate perioperative care among these children undergoing neurosurgery. In this regard, it is essential for the recognition of pediatric neuroanesthesia as a separate subspecialty. Currently, the focus of pediatric neurosurgery and neuroanesthesia appears to be restricted to the management of hydrocephalus, neural tube defect, and tumors. There are other common CNS issues in children like vascular problems, epilepsy, cerebral palsy, and traumatic brain injury. Pediatric neuroanesthesiologists and neurointensive care specialists should be involved in a multidisciplinary team that, hopefully, engages in research in the perioperative care of these children. In the present world of evidence-based medicine, literature on these topics appears to be limited as far as prospective randomized controlled trials are concerned. There is hope that with the evolution of this subspeciality, more meaningful research will be carried out and the spectrum of evidence regarding management widens.

The advanced training on pediatric neuroanesthesia can be imparted in the tertiary care centers where significant loads of pediatric neurosurgical patients are managed. It is only a matter of time that pediatric neuroanesthesia societies or special interest groups (SIGs) are formed. "Paediatric Neuroanaesthesia Network (PNAN)" is an active SIG for the cause which is part of "Neuro Anaesthesia & Critical Care Society (NACCS) of Great Britain and Ireland." Regular meetings/conferences showcasing the progress in this field and sharing knowledge across various platforms are expected to occur in the foreseeable future.

1.6 Conclusion

Neuroanesthesia has seen rapid evolutionary changes over the past century with significant pioneering contributions of physicians and surgeons alike. It can be ascertained with a reasonable level of confidence that pediatric neuroanesthesia, one of the newest entrants in the category of medical "subspecialties," offers much scope in clinical and research work for the anesthesiologist. Combining adequate knowledge and skill of pediatric anesthesia, neurosurgical anesthesia, and intensive care is essential to ensure that pediatric neuroanesthesia flourishes. This calls for establishing training programs to develop an appropriate curriculum taking into account the depths of the broad specialties involved. It is not unreasonable to expect significant contributions from this subspecialty in clinical management and research in the coming future.

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