12 History of Stereotactic Surgery in India

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Ancient Indian Literature

The earliest reference to any functional neurosurgery in world could be found in Indian mythology script Shiva Purana (http://is1.mum.edu/vedicreserve/puran.htm). It reflects a transplantation of elephant head on a human being (Ganesha).

Ganesha – the elephant-deity riding a mouse – has become one of the most common mnemonics for anything associated with Hinduism. The son of Shiva and Parvati, Ganesha has an elephantine countenance with a curved trunk and big ears, and a huge pot-bellied body of a human being. (*Figure 12-1*) He is worshipped as Lord of success and destroyer of evils and obstacles. He is also worshipped as the god of education, knowledge, wisdom, and wealth. The story of the birth of this zoomorphic deity, as depicted in the *Shiva Purana*, goes like this: Once goddess Parvati, while bathing, created a boy out of the dirt of her body and assigned him the task of guarding the entrance to her bathroom. When Shiva, her husband returned, he was surprised to find a stranger denying him access, and struck off the boy's head in rage. Parvati broke down in utter grief and to soothe her, Shiva sent out his squad (*gana*) to fetch the head of any sleeping being who was facing the north. The company found a sleeping elephant and brought back its severed head, which was then attached to the body of the boy. Shiva restored its life and made him the leader (*pati*) of his troop, hence his name "Ganapati." Shiva also bestowed a boon that people would worship him and invoke his name before undertaking any venture.

This narration highlights two important aspects of functional neurosurgery. One is the reproduction of a human being from dermis derived stem cell ("created a boy out of the dirt of her body") and second, the ultimate aim/achievement that could ever happen – "whole head transplant."

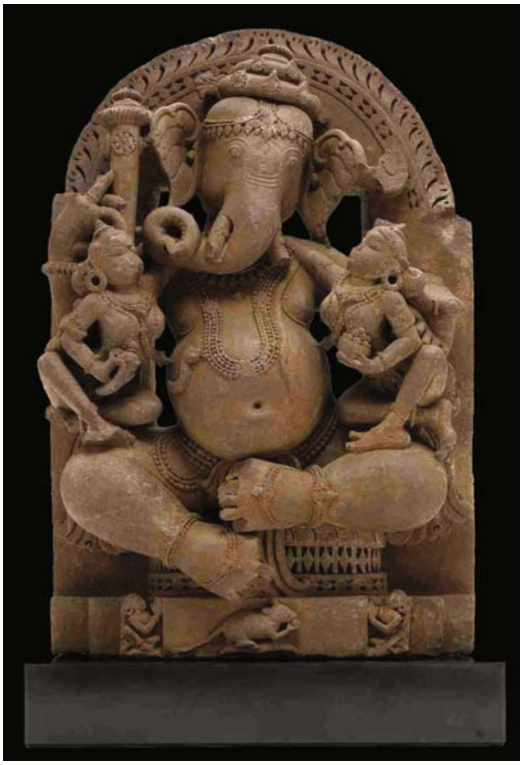
In another epic, it is documented that in 1800 BC, Jivaka (physician to the Lord Buddha) removed intracranial mass lesion through trephination.

Development of Stereotactic Surgery

Neurosurgery in India is a post World War II development, resulting from the keen desire of the new rulers of independent India, that the country should keep up with all the modern advances in every field of Neurosurgery [1]. It is interesting to note that many of the pioneers of Indian neurosurgery were exposed to stereotactic and functional neurosurgery, during their training abroad, which helped them to develop stereotactic neurosurgical specialty parallel with the international advances.

Stereotactic surgery developed in parallel across several centers in India. In this chapter, the development of each subset of functional neurosurgery is described separately along with the contributions of each center, rather than following the chronology of date. Most important references have been included but these are not necessarily all encompassing.

Figure 12-1
Lord Ganesha (Elephant God)



In the 1940s bold pioneers like Chintan Nambiar, a surgeon at Stanley medical college, Madras, used to perform freehand stereotactic lesions by using a template in the temporal region. While mentioning this in an oration, the pioneering stereotactic surgeon B Ramamurthi quotes "The surgeon was bold and the patients bolder." He performed 74 cases of chemopallidectomy using this free hand technique, out of which 27 had excellent results [2].

The first neurosurgical set up was established at the Christian Medical College (CMC), Vellore, in Tamilnadu, by Jacob Chandy. Chandy had obtained 2 years of training under Wilder Penfield at the Montreal Neurological Institute (MNI). In January 1949, equipped with neurosurgical equipments brought from Canada and an EEG machine, Chandy started the neurosurgical unit at CMC. He started with ten beds spread across medical and surgical wards. In 1950, he was joined by Baldev Singh, a neurologist. In 1962, CMC acquired the Bertrand stereotactic guide, with the help of which they performed surgeries for Parkinson's disease and epilepsies. Later in 1987, KV Mathai procured BRW frame. CMC became an established stereotactic unit, where till date around 1,800 stereotactic biopsies, 400 stereotactic craniotomies, 100 functional neurosurgical procedures, and 700 radiosurgical procedures have been performed. Vedantam Rajashekar, the present Head of the Department of Neurosurgery, and past president of the Indian Society of Stereotactic and Functional Neurosurgery, has been conducting stereotactic workshop to train young neurosurgeons [1].

Following on the heels of the department at Vellore was that at the Madras Medical College and Government Hospital; with the joining of Ramamurthi, in October 1950. Ramamurthi started his neurosurgical training with Rowbotham, in Newcastle upon Tyne, England. Subsequently he visited numerous centers across Europe and USA to gain wider experience. He also visited MNI and observed Rasmussen's and Penfield's work. Ramamurthi started neurosurgical unit with four beds which were increased to ten after 18 months [1]. Inspired by Irving Cooper's use of an inflatable balloon to make lesions in pallidum for the treatment of Parkinson's diseases, V Balasubramaniam and Ramamurthi performed surgeries using Cooper's balloon (1962) [3]. Under radiological guidance a balloon was introduced and left in place for 48 h. This was followed by alcohol ablation. After performing surgeries on 12 patients of movement disorders, they were discouraged with the results. Import restrictions and bureaucratic hurdles made further imports of these balloons difficult and hence they gave up this method. In 1960 Ramamurthi received an invitation for dinner with the Governor of Hyderabad, General Shrinagesh (*Figure 12-2*). It happened that the Governor was suffering from Parkinson's disease and had undergone unilateral lesion in London by Lawrence Walsh at Atkinson Morley Hospital.

Figure 12-2
Ramamurthi having dinner with, General Shrinagesh (Black Suit), Governor of Andhra Pradesh

He asked Ramamurthi if such facilities are available in India as he had started experiencing symptoms on the opposite side. Ramamurthi explained that though he had the necessary expertise, the equipments were not available. In those days it was very difficult to import any equipment or obtain foreign exchange to travel abroad. General Shrinagesh immediately called up the Prime Minister of India, Pandit Jawaharlal Nehru; it was 11 PM. The Prime Minister immediately agreed to Shrinagesh's suggestion to bring in Lawrence Walsh and Denis Williams (Neurologist) from England to conduct a workshop and training for movement disorders surgery. They also obtained permission for Walsh to leave his equipment behind after the workshop. Walsh and Williams came and stayed in Madras for 3 weeks during which they performed 40 surgeries and 30 neuroscientists took advantage of their expertise (*Figure 12-3*). On completion of the program as decided, they left the Leksell stereotactic apparatus and the lesion generator back in Madras [4]. This was a major impetus and from there on Madras became a leading stereotactic center where more than 1,700 procedures were performed between 1959 and 1975 (*Table 12-1*). Presently very little work is being done at this center after Ramamurthi and his team retired from the Madras Medical College.

In 1970, S Kalyanaraman, a young neurosurgeon in Ramamurthi's team from the Madras Medical College, reported simultaneous use of two stereotactic apparatus on the same patient. He used the Leksell stereotactic equipment in combination with the Sehgal stereotactic equipment to perform simultaneous targeting of intracranial structures. Sehgal's stereotactic equipment is a compact, burr hole based stereotactic device designed by Arjun Sehgal in India. The Leksell frame was used to align Sehgal's apparatus to the target on one side and on the other it was used to approach the target. The purpose was to obtain simultaneous recording from the thalamus, thus reducing the operative time. They also observed that the number of X-rays required to localize the targets were reduced [5,6].

RM Varma started a neurosurgical unit in the (then) All India Institute of Medical Health, Bangalore, in 1958. Varma's efforts led to the formation of the National Institute of Mental Health and Neurosciences (NIMHANS) out of this unit [7]. Varma was trained in Bristol and started performing lesions for Parkinson's disease using a unique free hand technique, through

Figure 12-3
Lawrence Walsh, Chief Nurse, Ramamurthi and Dennis Williams

Table 12-1
Stereotactic Surgery at Madras Medical College (1959–1975)

Thalamotomy	858
Amygdalotomy	480
Hypothalamotomy	122
Cingulumotomy	143
Basofrontal tractotomy	56
Dentatectomy	73
Leucotomy	5
Thalamolaminotomy	11
Capsulotomy	16
Pulvinotomy	4
Mesencephalc reticulotomy	2
Hypophysectomy	2

foramen ovale. Later on in 1980s, they obtained the Leksell stereotactic equipment and recently a gamma knife unit.

HM Dastur, started stereotactic surgery at King Edward Memorial (KEM) Hospital, Bombay (Mumbai) in 1959. The initial surgeries were performed using Oliver's guide. Narabayashi visited KEM hospital in 1962 and lent the design of his stereotactic frame for fabricating a local frame on similar lines. Later on in 1975, Dastur joined Jaslok Hospital, Bombay (Mumbai), where he continued to perform stereotactic surgery using a Reichert-Mundinger frame. In another center at Bombay Hospital, SN Bhagwati started stereotactic surgery with Mckinney's apparatus from 1962 and this was replaced by Leksell's frame in 1964.

Multiple centers started practicing stereotactic surgery in the 1970s. These include Post Graduate Institute of Medical Education and Research (PGIMER), Chandigarh (1974), with Mckinney frame, All India Institute of Medical Sciences (AIIMS), New Delhi (1977), with Leksell frame and Shri Chitra Tirunal Institute for Medical Sciences and Technology (SCTIMST) with Leksell frame [2,8].

In 1991 Mr. Bose, an engineer and Apte, a neurosurgeon from Pune, developed an indigenous arc centered stereotactic apparatus. Three revisions have been made to this initial model, which is now compatible for CT and MRI guided procedures. They followed this by manufacturing a radiofrequency lesion generator in 1996. The prices of these equipments are considerably lower than standard stereotactic frames and hence have become popular for performing biopsies and other stereotactic procedures. Presently 40 neurosurgical units have stereotactic equipment and they perform various levels of stereotactic procedures from biopsy to functional neurosurgery.

The Indian Society of Stereotactic and Functional Neurosurgery was formed in 1997. Its first meeting was held in Delhi with Balasubramaniam as president and Rajashekar as Secretary. In 2007 the tenth meeting of the society was held in Kolkata. This is a rapidly expanding society with the current membership of more than 100 members.

Stereotactic radiosurgery was first introduced in India at the Apollo Hospitals, Chennai, using Linac based X-knife system. Linac based radiosurgery is offered at multiple centers including Bombay Hospital and Jaslok Hospital, Mumbai. Gamma Kinfe was introduced at Hinduja Hospital, Mumbai, in 1997 [9]. This was soon followed by similar units at AIIMS and VIMHANS in New Delhi, and later on at other centers including Vellore, NIMHANS, R&R (Army Hospital, New Delhi), PGIMER (Chandigarh) etc.

Epilepsy Surgery

In the early days of stereotactic and functional neurosurgery the enthusiasm of the neuroscientists could not be contained. Virtually lesions were placed in every part of the brain for varied disorders ranging from epilepsy to psychiatric illness [10]. To further understand the development drivers of these surgeries, we need to look into India's social and economical background of that period. A recent (2006) survey (http://www.prb.org/Articles/2006/CommunityBasedHealthInsuranceShowsPromiseinIndia.aspx) showed that only 11% of Indian population had some kind of health insurance, this could not have been more than 2–4% in 1960s. Thus the medical treatment had to be funded by the patient themselves or they had to use government or municipal hospitals to treat them. Though these hospitals were supposed to be providing free medical treatment, the medicines (especially the expensive ones) had to be purchased by the patient. Paradoxically the cost of surgeries in these hospitals was far less than prolonged medical treatment. In a report on epilepsy research, Mathai [11] mentions that follow-up studies indicated that where the person was receiving more than two drugs the cost of the therapy would come >2 $/month and only 10–15% of the patients had the resources to afford this. Hence in developing countries financial insufficiency formed an added indication for surgical therapy in the control of seizures.

Chandy, who had trained at the MNI, started epilepsy surgery in CMC, Vellore in 1949. He was joined by Baldev Singh, a neurologist, who had interest in epilepsy and was equipped with an EEG machine to diagnose and manage epilepsy. Singh and Chandy [12] in an exhaustive study of delta waves in 800 EEG records at CMC, commented on their characteristics and localizing value. Those were the days when EEG was the only non-invasive investigation for brain disorders (including tumors). During 1949–1990, 141 epilepsy surgeries were performed at CMC [13]. They performed topectomy and lobectomy for suprasylvian epilepsy; for temporal lobe epilepsy (TLE) the surgical procedures done were topectomy, temporal lobectomy with amygdalectomy, temporal lobectomy with amygdalohippocampectomy, and only amygdalectomy. Hemispherectomy was done for cases with multilobar epilepsy. Temporal lobe resections were done based on the scalp EEG, sphenoidal studies, neuropsychological assessment and the intraoperative ECoG and depth electrode studies. Total or near total seizure control was obtained in 53% patients and a satisfactory outcome in 20% patients. They found that mental retardation, pre operative scalp EEG and post excision electrocorticography were predictors of outcome.

In Madras, Ramamurthi developed an excellent team. He along with Balasubramaniam, Kalyanaraman and Kanaka as neurosurgical colleagues; Arjundas, Jaganathan and later on Sayeed as neurological colleagues, Vriddhagirinathan the psychologist and Valmikinathan, neurochemist developed a comprehensive epilepsy surgical program. They reviewed the literature and noted that Falconer had obtained good results by standard temporal lobectomies in three fourth of the patients [14]. Narabayashi and Chitanondh had reported 50% seizure control and improvement in behavioral disorders in patients undergoing amygdalectomy. Ramamurthi felt that massive temporal lobectomy, only to ablate these medial structures, is a mutilating procedure. They treated complex partial seizures with proved medial temporal focus with stereotactic lesions rather than by a full temporal lobectomy [15–19]. They established the details of localization of epileptic focus by careful pre and postoperative observations of their neurological colleagues. In a paper published in 1979 [20], Ramamurthi shares his experience of 56 cases that he operated. The patients included, suffered from purely TLE, TLE with secondary generalization or TLE with focal seizures. EEG studies including sphenoidal and depth electrode recordings were performed prior to surgery. Based on these findings, stereotactic lesions of 600–800 m^3, were made in the area of maximum abnormality. He found that 26 of the 56 patients became seizure free and eight cases required reoperation. He commented that this procedure was useful in patients who had bilateral TLE or contralateral previous temporal lobectomy, as it preserved the hippocampus and thus the memory. Mathai, in CMC Vellore, also performed amygdalectomy through a craniotomy for similar reasons. They performed intraoperative corticography and depth studies from amygdala to plan their surgical resections. They concluded that when the seizure discharges are from the cortex rather than amygdala, excision of the amygdala only reduces the intensity of cortical activity. However, when the epileptiform discharges are primarily from the amygdala, amygdalectomy alone might suffice; especially when an electrocorticographic seizure can be produced by stimulating the amygdala [11]. In Bombay (Mumbai), at KEM hospital Dastur, assisted by neurologist Anil Desai, performed epilepsy surgery including temporal lobectomy and hemispherectomy. He continued his work after joining Jaslok Hospital, where he was assisted by Mrs. PN Wadia, neurophysiologist in performing epilepsy surgery. Corticography and depth recordings during the surgery were also performed.

During 1960s depth electrodes and corticography were used routinely for epilepsy surgeries. Arjundas observed that the depth electrode supplements information obtained from scalp EEG in identifying the epileptogenic focus and also reveals foci not evident in scalp EEG records [21]. Kanaka and Balasubramaniam found that depth studies were useful in understanding the propagation of epileptic discharges. They found that depth electrode study along with electrocorticography also provided precise localization of the epileptic focus. They used this information for planning appropriate surgery [22].

Kalyanaraman had obtained PhD degree from Edinburgh, University on “Anatomical and Physiological studies on the internal capsule and adjacent diencephalic structures during human stereotaxy.” Based on his work and the observations of Gillingham [23], Kalyanaraman postulated that in an area in the posterior limb of the internal capsule, medial to the pyramidal tract where lie the corticospinal fibers that form the common pathway for the epileptic seizure. A bilateral internal capsulotomy should control clinical seizures without causing pyramidal signs and without producing electroencephalographic improvement. To test this hypothesis, they performed bilateral internal capsulotomy on seven patients with intractable grand mal epilepsy. They had good outcome (comparable to Engel grade I and II) in three patients, considerable reduction in seizure frequency in one and poor outcome in two. One patient died of pneumonia postoperatively. None of these patients had significant permanent morbidity [24,25].

Mathai postulated that in patients suffering from generalized seizures or focal seizures arising from significant (eloquent) cortical areas, which cannot be excised without producing serious neurological deficit, interruption of propagation pathways may modify the frequency and pattern of the seizures. They performed stereotactic lesioning of ansa and fasciculus lenticularis. Bertrand stereotactic guide was used and the target chosen was 1 cm behind AC and 1.5 cm lateral. A leucotome was used to make a lesion of 0.5–0.8 cm. Scalp and depth EEG recordings were obtained during this stage. They had variable results, ranging from good seizure control to reduction in seizure frequency and severity. They concluded that because of the multiple propagation pathways in epilepsy these procedures may only temporarily modify the clinical seizure pattern. However, in seizures where the frequency is once a day or more such procedures are of value. Destruction of ansa and fasciculus lenticularis bilaterally for generalized cerebral seizures and unilaterally for focal cortical seizures seems to alleviate, although not fully, the intensity and frequency of seizures [26].

Few epilepsy surgeries were performed during 1970–1990. Radhakrishnan, epileptologist, started an epilepsy surgery program at the SCTIMST. This was a complete program with facilities for invasive recording, neuropsychology, video EEG and nuclear medicine. Their initial focus was on temporal lobe epilepsy. From March 1995 through February 2002, they performed 394 epilepsy surgeries, 370 of them were anterior temporal lobectomy with amygdalohippocampectomy for refractory temporal lobe epilepsy. They reported 78% seizure freedom at 2 years follow-up [27]. Epilepsy surgery was started in AIIMS, by VP Singh [28], at Jaslok Hospital by P Doshi and at Hinduja Hospital by CE Deopujari and BK Misra in the late 1990s. All these centers have facilities of state of the art neuroradiology, neurophysiology (including prolonged video EEG), nuclear medicine departments for SPECT and PET scans, neuropsychologist, epileptologist and functional neurosurgeon.

Movement Disorders Surgery

Movement disorders surgery has had the most colorful history in any account of functional neurosurgery. This is true for India as well. Enterprising neurosurgeons used varied techniques from free hand technique to frame based systems, unilateral and bilateral lesions, even simultaneous bilateral lesions; alcohol to radiofrequency lesioning and from pallidum to field of Forel, to ameliorate movement disorders.

Balasubramaniam and Ramamurthi started performing chemopallidectomy using Cooper's balloon in 1962 as mentioned earlier [3]. From 1964 they used the Leksell's apparatus to perform thermal lesions for movement disorders [29]. Kalyanaraman, performed bilateral simultaneous thalamotomies in patients with various movement disorders. They observed that the complication rate was acceptable and no greater than staged procedures in patients with advanced Parkinson's disease. In patients with bilateral intention tremors this formed a good surgical option as it avoided double hospitalization [30]. Using Sehgal's stereotactic apparatus he used to perform bilateral simultaneous recordings as described earlier.

During surgery an opaque marker was introduced into the site of the lesion. Immediate postoperative X-rays were taken and the exact location of the lesion was charted with the help of the atlas prepared by Schaltendrand and Bailey. This served not only to assess the accuracy of lesion placement but also to correlate the result of surgery with the site of the lesion. They noted minor differences in the anatomical calculations of deep brain structures in different races and groups [31].

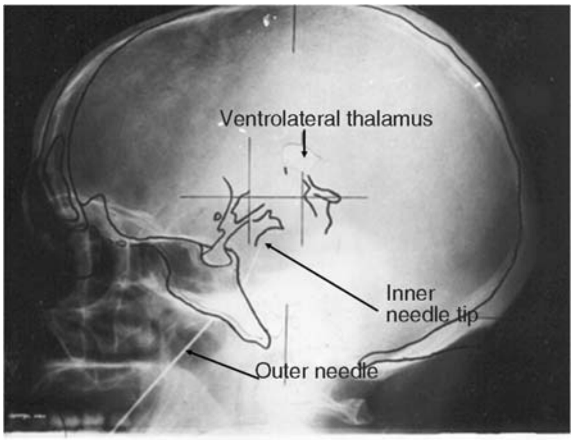
Though in 1970s, the number of surgeries for Parkinson's disease started decreasing, due to the cost constraints of prolonged Levodopa therapy excellent surgical benefits (especially for unilateral disease) Madras group continued to perform surgeries for Parkinson's disease.

Another unique area of interests was the treatment for cerebral palsy. Following the work of Narabayashi [32], Balasubramaniam and his colleagues operated on a large number of cerebral palsy patients. As their experience evolved they chose different targets depending on the predominant symptom complex. For Rigidity they made a lesion in the area below the ventrolateral nucleus (VL); for dyskinesias they used variety of targets including the ventralis intermedius nucleus (VIM), the centromedian nucleus (CM) and the dentate nucleus of the cerebellum. As most of these surgeries were done under general anesthesia verification of the electrode placement by stimulation, as done in Parkinson's disease was not possible. Stimulation was still done to exclude electrode placement in the corticospinal tract [33]. They later on introduced stereotactic dentatectomy for patients with predominant spasticity. They found that VL and sub VL lesions were effective for rigidity, whereas for patients with a mix of rigidity and spasticity these lesions had to be supplemented by dentatectomy. Patients with sensory induced involuntary movements benefited from centromedian thalamotomy [34].

For severe hyperkinetic disorders, Kanaka found hypothalamotomy to play a distinct role in their management. She observed that it works because the area destroyed forms part of the limbic system. It seemed to be more on the "effector" side. It does not cause any morbidity. In the management hyperkinetic behavior disorders the first target to be destroyed must be the amygdaloid nucleus. If this operation fails, then hypothalamotomy may be done as the next operation [35].

Varma (1964) in Bangalore developed a free hand technique of lesioning the thalamus for Parkinson's disease. He modified the technique of Arthur Ecker and Theoder Perl [36] for this surgery. The technique involved use of two needles, outer 19G, to cannulate the foramen ovale; and the inner, 26G to perform chemothalamotomy. The outer needle had a slight curve at the end to help direct the inner needle to the desired position (*Figure 12-4*). Varma used external landmarks to do away with ventriculography. He used lead pellets placed on the external canthus of the eye and in the internal auditory meatus to serve as markers. Lateral and AP radiographs were obtained after the introduction of the needle. A topograph was created outlining the above landmarks in relation to the ventero-lateral thalamus (based on an atlas). This was then overlain on the lateral x-ray and the distance between the needle and the target obtained. Appropriate radiographic and anthropometric corrections were applied to calculate the relationship of the needle to the target and the final position of needle adjusted. Varma notes that in many patients the tremor used to get arrested when the needle reached the target. This was then followed by chemothalamotomy with absolute alcohol [37]. His work was later on reviewed with MRI imaging of the patients operated, by

Figure 12-4
Varma's Foramen Ovale "Thalamotomy" for PD. Outer and inner needle seen in situ, with cranial landmarks outlined



Uday Muthane [38,39]. Muthane analyzed the site of the lesion by MRI and, in one case, postmortem examination. He noted that the lesion was actually placed 1.5 cm below the thalamus and it coincided with the subthalamic nucleus.

Stereotactic surgery was performed initially at CMC, Vellore by the free hand technique and later from 1961 onwards using Bertrand's frame. Parkinson's disease and dystonia were the main indications. The initial target used was globus pallidum, which was, later on changed to the thalamus. The free hand technique involved localizing the foramen of Monro using pneumoenchephalogram and pallidal target was calculated based on stereotactic atlas derived coordinates. AP and lateral radiographs were used for localization. The lesions were made using absolute alcohol in incremental methods whilst checking for neurological deficits (Mathai KV, personal communication).

In Bombay (Mumbai), Dastur started performing lesions in thalamus, pallidum and field of Forel for dystonia at the KEM hospital in 1959 (Dastur HM, personal communication). Desai, neurologist associated with KEM neurosurgical department, visited Narabayashi in 1962, to assist Dastur in performing movement disorders surgery. The program received further impetus following Narabayashi's visit. Dastur recounts a very interesting experience. They planned to perform a Cooper's lesion for a patient with severe "hyperkinesis." Following surgery, the patient had a remarkable improvement. However, on postoperative x-ray analysis they found that their lesions were not in the intended area but the lesions were more in the ventrolateral thalamus above the CA-CP plane. Gajendra Sinh, neurosurgeon at the Jaslok Hospital, used to call this a KEM lesion. The lesions were made using myodil and wax (*Figure 12-5*). In 1974 Sinh invited Laitinen to visit Jaslok Hospital. Laitinen demonstrated his pallidotomy operations, which were then followed up by Sinh. After the 1980s movement disorders surgery almost stopped following remarkable improvement in medical management.

Figure 12-5
Notings of "KEM thalamotomy" by Dastur

In another unit in Bombay (Mumbai), Bhagwati and his colleagues performed thalamotomies for Parkinson's disease in 110 cases. They were also convinced about the efficacy of bilateral lesions and 30 of these patients had undergone bilateral lesions. They reported an interesting observation of reactivation of successfully abolished tremors on thalamic stimulation whilst performing surgery for the second side in Parkinson's disease. In five of the thirty patients who underwent staged (minimum interval 6 months) bilateral thalamotomy, tremors recurred on the side of the second thalamotomy, i.e., on the ipsilateral side. In three patients, they performed a repeat lesion for the control of these tremors, but the patients had a rather stormy convalescence and developed drowsiness, confusion, dysarthria with one of them developing pseudobulbar palsy, in the next two patients simultaneous bilateral lesions were not made. The recurrent tremors persisted in these two patients [40]. Kalyanaraman also had similar experience in patients undergoing bilateral thalamotomy. Bhagwati earlier used diathermy to make lesions but later on switched over to cryo lesioning [41].

Once again, like other places in the world, interest in Parkinson's disease surgery waned after the introduction of Levodopa. Surgery for movement disorders surgery was revived in 1997. Doshi after his training in Europe started performing pallidotomy. However, within a short period (1998) he switched over to deep brain stimulation surgeries [42]. He and his colleagues observed that STN DBS can produce depression in an occasional patient [43], which was later on accepted as an important side effect in almost 8–18% of STN DBS patients [44,45]. SCTIMST also started performing pallidotomy and deep brain stimulation around the same time. Presently movement disorder surgery is being performed in Mumbai, Hyderabad, Banglore, Trivandrum and Delhi.

Surgery for Chronic Pain

Roy offered stereotactic cingulotomy for intractable terminal cancer pain. He used Oliver's apparatus. The needle was positioned to produce a lesion 2–4 cm posterior to anterior tips of the ventricles and 2 cm in vertical height from above the ventricles. 0.1 ml of carbolic acid with myodil was used in making the lesion. The maximum relief was noted approximately for 2 months after the operation. After this period, the relief of pain was not complete and analgesics were again required. They advocated this surgery for terminally ill cancer patients [46].

Dorsal cordotomy was the preferred procedure in patients suffering from pain of incurable malignancy in the lower half of the body. However, when the upper half of the body was involved intracranial targets were chosen. Ramamurthi [47] notes that intractable pain due to lesions other than malignancy was not often seen in Indian neurosurgical practice. The incidence of oropharyngeal cancer was very common in South India and advanced cases reported with intractable pain. In such cases section of the trigeminal or the glossopharyngeal nerve was fraught with grave risks especially due to deglutition difficulties with resultant risk of aspiration. Kalyanramana and Ramamurthi studied the neurophysiology of the sensory relay nucleus [48]. From the atlas of Schaltenbrand and Bailey [49] they calculated that the facial area of the sensory relay nucleus of the thalamus was centered on a point 4 mm in front of the center of the posterior commissure, 4 mm above the intercommissural line and 13 mm lateral to the midsagittal plane. Whereas, the termination of the quintothalamic tract into the sensory relay nucleus was calculated to be centered around a point 3 mm in front of the posterior commissure, on the intercommissural line and 10 mm lateral to the midsagittal plane. They used neurophysiological guidance to further refine their target localization. They noted that though sensory responses could be obtained from the internal capsule or other parts of thalamus, the threshold of this response was lowest when the electrode was in the sensory relay nucleus. They also found that microelectrode recordings showed evoked potentials from peripheral stimulation. They initially made large lesions of 8 mm, five times, in the first few patients. However, later on they made only one lesion of 8 mm in the sensory thalamus and an additional lesion in the quintothalamic tract region if pain relief was not adequate. As most of these patients suffered from terminal cancer, they died after a few months and had adequate pain relief till they lived. Two patients who had post herpetic neuralgia continued to have pain relief at a follow-up of 6 months [50]. They also performed cingulotomy and hypothalamotomy for pain relief [51].

Psychiatric Disorders Surgery

There was a great interest and enthusiasm amongst Indian neurosurgeons in the field of psychiatric disorders surgery as early as 1940. Balkrishna Rao in Bangalore, performed prefrontal leucotomies on patients selected by Govindaswami [52].

BK Anand, a neurophysiologist, participated in the study of the role of the hypothalamus and limbic system in the regulation of feeding behavior conducted by John Fulton and JR Brobeck [53,54]. They discovered, what is since known as, the hypothalamic feeding center. On returning to India, he worked at the Lady Hardinge Medical College, New Delhi and later, at the Department of Physiology, AIIMS, New Delhi [55]. He introduced new experimental techniques and approaches for the study of brain and behavior in India. These include the methods of stereotactic placement of electrodes for making local electrolytic lesions, electrical stimulations, recording of depth EEG, evoked potentials and single unit potentials with microelectrodes and the usage of unanesthetized and free moving animals for behavioral experiments. Manchanda et al. [56] observed that electrical stimulation of perifornical regions of hypothalamus in the carnivore cat evoked different varieties of aggressive behavior: flight, defense, attack. These led other researchers and neurosurgeons to explore the vast field of psychiatric disorders surgery.

During his training with Rowbotham, Ramamurthi used to visit St. Lukes Hospital at Midlesborough, where Rowbotham used to perform prefrontal leucotomies. He found that it was successful in more than 60% of the patients. He decided to undertake this upon return to India. Ramamurthi found that the psychiatrists in South India were forward looking and readily referred cases for surgery [10]. For severe depression, Ramamurthi performed a stamp size lesion, extending from 0.7 to 3.0 cm from the midline and 0.8 to 2.8 cm in front of the tip of the anterior clinoid process in the subfrontal region using the diathermy [57]. There was an instantaneous improvement, with some patients describing that “a great load has been lifted off my chest.” Most patients benefitted [58]. In Obsessive Compulsive neurosis, lesions were made in the cingulum. The results were good and long lasting. In some patients, where the results were not as good as expected another lesion was made in the subfrontal region or the cingulum [59–61].

Another interesting indication for psychosurgery was drug addiction. Thirty two cases suffering from drug addictions (alcohol, morphine and pethidine) were operated by Balasubramaniam during 1970–1972. Surgery was done under general anesthesia. Stereotactic localization was performed using pneumoencephalography and carotid angiography. These investigations were essential to determine the thickness of the corpus callosum for making precise lesion in the cingulum, clearing the corpus callosum. The target was selected in line with the foramen of Monro, midway between the pericallosal and callosomarginal arteries. In the coronal plane, the center of the target was 7 mm from the midline. Destruction was done in all cases by injection of myodil, oil, and wax mixture prepared according to the formula of Narabayashi [62]. Both sides were done at one sitting. Postoperative x-rays were taken to confirm the accuracy of the lesion. Of the twenty eight cases followed up for more than 6 months, 22 had been addiction free [63]. Recounting his experience Ravi Ramamurthi says that he found that this was most effective for pethidine addicts. He also mentioned that it was only offered to the patients who were inclined to be weaned off their addiction but had failed. The cingulotomy would take away the affective part of their withdrawal symptoms.

Balasubramaniam and his colleagues also performed stereotactic amygdalotomy for aggressive behavior in children and adults. Such behavior ranged from continuous severe violent acts towards others, pyromania, destructive tendencies, to episodic attacks of behavior disorders or severe degrees of restlessness. The aim of the operation was to destroy the amygdaloid nucleus or its connections so as to make the patient more manageable either with or without drugs. During 1964–1967, they performed 50 operations on 44 patients; most of them bilateral. The center of the amygdaloid nucleus was considered to be 4 mm in front of the apex of the temporal horn. Two reference points were taken. The first 18 mm below the CACP plane, 6 mm anterior to midcommisural plane and 22 mm from the midsagittal plane. The second reference point was 4–5 mm anterior to the apex of the temporal horn. The author's preferred the second reference point. In case there was significant cortical atrophy, the first reference point was used. The lesion was made either by diathermy coagulation or Bertrand loop. Diathermy coagulation was done with an 8 mm. electrode, the area of destruction being approximately 200 m^3. For the amygdaloid nucleus nine lesions were made. The total volume would be about 1,800 m^3 which was slightly greater than the volume of the amygdaloid nucleus which is about 1,200 m^3. The lesions made with Bertrand loop were much smaller measuring 500 m^3. In 30 operations diathermy was employed and in 19 the Bertrand loop. In one operation both were used. They found that patients having aggressive behavior associated with epilepsy had a better outcome as compared to those suffering from post encephalitic illness aggression [64].

Another target of interest was the posterior hypothalamus. Stereotactic intervention into the posterior hypothalamus was noted to give satisfactory results for controlling both aggressive, violent behavioral disorders and intractable pain. From the endocrinological point of view, this procedure activates the hypothalamic-hypophyseal axis only temporarily, without causing any serious dysfunctions [65]. Based on these observations Balasubramaniam and Kanaka performed hypothalamotomy on patients who failed to improve after amygdalotomy [66–68]. During the subsequent years, 522 surgeries were performed for aggressive behavior disorder, 402 were bilateral amygdalotomies, and 120 posteromedian hypothalamotomy [69].

Neural Transplantation

Stimulated by the reports of A Bjorklund and GD Das at the first congress of the International Brain research organization held at Laussane, Switzerland in 1982, Gopinath (neuroanatomist), Tandon and Mahapatra (neurosurgeons) with Nayar and Mohan Kumar (neurophysiologist) set up a unit to study neural transplantation, with the help of the Department of Science and Technology. They studied neural transplants in rat and primates. Transplantation of embryonic neocortex was performed into cerebellum, lateral ventricle, third ventricle, striatum, hippocampus, tectum and the anterior chamber of the eye in rat. Behavioral and electrophysiological studies were carried out before and after transplantation. Transplantations were also performed in rhesus monkey's striatum, neocortex and cerebellum for standardization. Parkinson's disease model was produced in rhesus monkeys using MPTP. As it was difficult to maintain a bilateral Parkinson's disease model, a unilateral disease model was created. After stabilizing the signs and symptoms for 4–12 weeks, they were grafted with fetal substantia nigra into the striatum using stereotactic techniques. Four monkeys were transplanted. Gopinath [70] notes that three of the four monkeys improved sufficiently to handle food while one had to be sacrificed due to complications [71]. Similar transplant program was also initiated at NIMHANS [72] in 1989 and at the post graduate institute of basic medical sciences, Madras [73,74].

Presently, various centers in Bangalore and Delhi are performing studies on Mesenchymal stem cell transplantation for Parkinson's disease and spinal cord injury.

Currently, India is experiencing a renaissance of stereotactic and functional neurosurgery. Imports of equipment has become easier and the present generation of neurosurgeons have the best of both the worlds; extensive clinical experience in India as well as advanced training in specific fields from various centers around the world. There is an increase in understanding and interest in developing India into a global health care provider. Realizing this, a large number of private hospitals have begun to invest in state-of-the-art equipment, thus providing an important platform for the development of this subspecialty.

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