10 History of Stereotactic and Functional Neurosurgery in Canada

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Introduction

Functional neurosurgery in its broadest sense includes the surgical treatment of pain, movement disorders, epilepsy and psychiatric conditions. Canada has played a rich and pivotal role in the development of these areas. Wilder Penfield, Herbert Jasper, Ted Rasmussen, Claude Bertrand and Ron Tasker – to mention a few – are names that are familiar to most neurosurgeons who are involved in the practice of functional neurosurgery. This chapter will review some highlights in the development of functional neurosurgery in Canada with an emphasis on stereotactic surgery and epilepsy surgery.

Epilepsy Surgery and the Montreal Neurological Institute

In 1928 Edward Archibald, professor of surgery at McGill University, brought Wilder Penfield and William Cone to Montreal, to develop neurosurgery at McGill University. Their clinical work started at the Royal Victoria Hospital and the Montreal General Hospital in Quebec [1].

Penfield [2] had wanted to establish an institute for the scientific study and treatment of neurological disorders and in 1932, the Rockefeller Foundation granted 1.2 million dollars to McGill University for this purpose. This money along with contributions from the city, province and other donors allowed construction of the Montreal Neurological Institute (MNI), which opened in 1934 as a 50 bed hospital for the investigation and treatment of brain disorders.

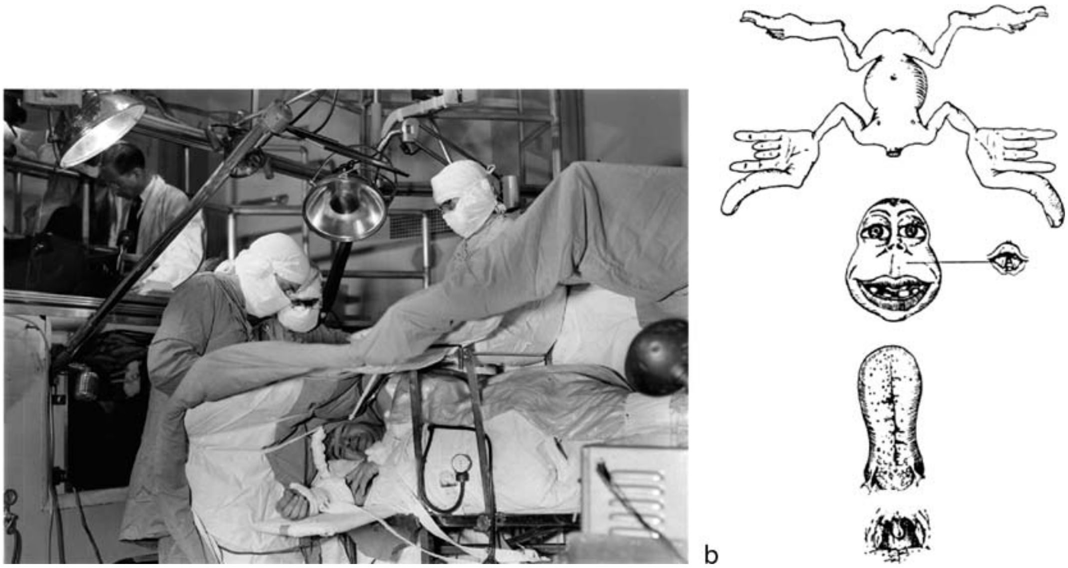
Penfield's background included study with Sherrington and Osler at Oxford, Holmes and Greenfield at Queen Square, Cajal and Hortega in Madrid, and Foerster in Breslau. With Foerster he learned the cortical stimulation and excision techniques that he would apply to the treatment of epilepsy.

Penfield carried out his first procedure for focal epilepsy at the Royal Victoria Hospital in November 1928, on a young man with post-traumatic epilepsy resulting from a head injury with subdural hematoma and brain contusion after a fall from a horse. At the first operation the motor strip was identified by cortical stimulation and a small adjacent corticectomy was performed. Seizures continued and this man underwent a total of three epilepsy procedures culminating in a wide temporal resection – Penfield's first temporal lobe resection for epilepsy [3].

Penfield meticulously studied his patients, both clinically and in the operating room and kept detailed records of the results of cortical stimulation. In 1937, Penfield and Boldrey [4] published their results of cortical stimulation mapping in 163 patients marking the first appearance of their motor-sensory homunculus (➜ *Figure 10-1a, b*). Many of our current concepts of cortical localization are based on Penfield's work [5].

By the early 1950s, Penfield [6] had recognized the unique nature of temporal lobe epilepsy, and introduced the concept of mesial temporal

Figure 10-1
(a) Penfield and his surgical team operating on an epilepsy patient who is awake under local anesthesia, in order to identify the epileptic focus by brain mapping. Herbert Jasper, in the glazed gallery, records the electrocorticogram (from Brain vol. 130, figure 10, 2007). (b) The ''homunculus'' showing areas of cortex related to body movements as evoked by stimulation of the cortex (from Penfield and Boldrey [4])


a b

sclerosis; at that time attributed to herniation of the mesial temporal structures over the edge of the tentorium during difficult childbirth. Penfield and Jasper's book "Epilepsy and the functional anatomy of the human brain" was published in 1954 and represented a wealth of information on the clinical presentation of epilepsy, observation related to memory, localization of language and surgical aspects of epilepsy treatment [7] (*Figure 10-2*).

Penfield was responsible for the recognition of epilepsy as a surgically treatable disease. He utilized electrical stimulation of the cortex in patients undergoing craniotomy under local anesthetic and thereby improved the safety of cortical excisions near eloquent cortex. His technique of subpial dissection resulted in less residual damage and gliosis after corticectomy. This is now a standard technique for epilepsy surgeons.

Penfield [1] was Director of the MNI from 1934 to 1960, succeeded by Theodore Rasmussen from 1960 to1972. Rasmussen became Professor

Figure 10-2
Penfield and Jasper [7] with manuscript of their book ''Epilepsy and the Functional Anatomy of the Human Brain''(from Can J Neurol Sci18:540 figure 6)

and Chairman of Neurology and Neurosurgery at the MNI in 1954, coming from the University of Chicago where he was had been Professor of Surgery since 1947 [8].

Rasmussen [9–11] added to the MNI's contributions to the surgical treatment of epilepsy. In his years there he probably performed more operations for epilepsy than any other surgeon of his time. These cases were meticulously followed and his outcome publications report some of the longest follow-ups of epilepsy surgery patients.

Rasmussen [12,13] together with Juhn Wada validated the application of the carotid amytal test for lateralization of language function and extended its value by using it for the assessment of memory in candidates for temporal lobe surgery. This is still an important means of testing memory adequacy and reserve in candidates for temporal lobectomy.

Rasmussen's name became attached to the entity of chronic localized encephalitis associated with intractable focal seizures (Rasmussen's encephalitis); first described by Rasmussen et al. [14] in 1958. Rasmussen and others [15–17] described the condition of cerebral hemisiderosis as a late complication of anatomical hemispherectomy, and introduced functional hemispherectomy as a strategy for preventing it.

The MNI continues in its role, not only in the surgical treatment of epilepsy, but also in its role as educator with the training of numerous Canadian and international neurosurgeons, and neurosurgical fellows in these techniques.

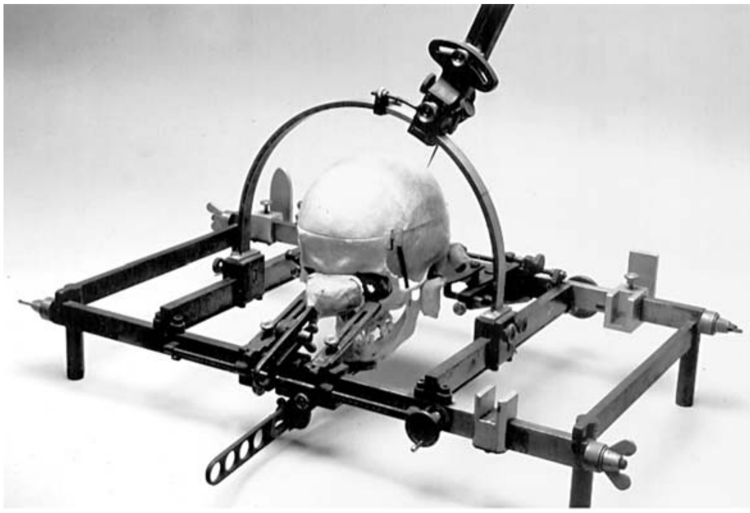
Stereotactic and Functional Neurosurgery at the MNI

Gilles Bertrand and John Blundell started the functional stereotactic program at the MNI when they performed the first stereotactic pallidotomy in 1958 and the first thalamotomy in 1959 [18]. Gill Bertrand started at the MNI as a resident in 1951 (*Figure 10-3*). John Blundell was invited to join the MNI group in 1957. He was sent to study with Lars Leksell in Sweden and to bring

Figure 10-3

(a) Dr. Gilles Bertrand inserting a microelectrode into a patient with Parkinson's disease. (from Can J Neurol Sci 14:542 figure 8). (b) Gilles Bertrand (*left*) with Herbert Jasper (*right*) in 1988. They collaborated from 1964 to 1966 on pioneer studies of microelectrodes recording from basal ganglia neurons in patients undergoing stereotactic surgery for Parkinson's disease. (from Can J Neurol Sci 26:228 figure 8)

Figure 10-4
The Jasper and Hunter stereotactic instrument. (from Neurosurgery 2004, 54(5):1246 figure 3)

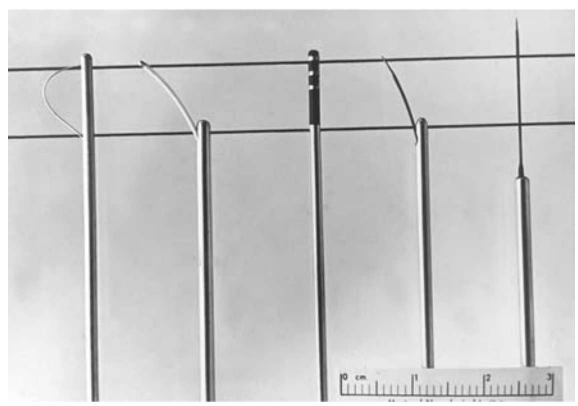


back a Leksell stereotactic instrument. Prior to this, Drs. Herbert Jasper and John Hunter had constructed a stereotactic frame for human use – but this was never used for clinical purposes. This frame was designed to mount on the operating table with the patient in a sitting position. It was held in place by earplugs, orbital bars and a plate under the upper teeth rather than by skull pins (*Figure 10-4*).

They settled on the leukotome of Claude Bertrand for lesion production after studying thermocoagulative lesions in animals and finding great variability of lesion size with identical lesion parameters. At the suggestion of Jasper in 1963 they started using microelectrode recording, and the group adopted a system with a straight microelectrode and one with a curved side arm to record from areas around the central exploring electrode (*Figure 10-5*).

This group was one of the first to develop a computer program to assist with operative mapping. It allowed operative stereotactic data to be mapped onto digitized versions of various brain atlases that were expanded or shrunk to match the intercommissural distances of the respective patients [19,20]. Oblique trajectories could be followed interactively through the different parasagittal planes, and operative physiologic data could be registered to stimulation points for later reference. The leukotome was modeled on the computer screen to allow lesions to be accurately planned and mapped [21,22].

Figure 10-5
Leukotome (far *left*) used for lesion making, curved stimulating electrode (second from *left*) for performing macrostimulation, three-step electrode (center) used for macrostimulation and evoked potentials, straight and curved tungsten microelectrodes (*right*). (from Neurosurgery 2004, 54(4):1246 figure 4)



As with all neurosurgical centers, the MNI saw a decline in the number of stereotactic procedures performed for Parkinson's disease after the introduction of L-dopa. Surgery for other movement disorders patients, mainly essential tremor and dystonia, continued. Abbas Sadikot joined Gilles Bertrand in 1993 and they worked together for a year prior to Bertrand's retirement from clinical practice. The MNI group continues it work on computerized brain atlases for use in functional neurosurgery.

The Leksell stereotactic frame, which was used for their stereotactic procedures, underwent modifications over time. Initial modifications by Bertrand allowed x-rays to be taken through the frame. Later, Andre Olivier made changes to facilitate the insertion of orthogonal electrodes and to make it compatible with angiography and MRI. This became the Olivier–Bertrand–Tipal or OBT frame (OBT frame, Tipal Instruments, Montreal).

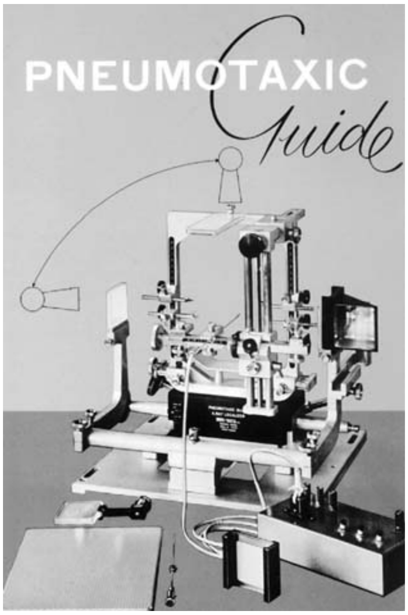
Functional Neurosurgery in Montreal – Hôpital Nôtre-Dame

Claude Bertrand was one of the pioneers of stereotactic and functional neurosurgery in Canada. Born in 1917, he obtained his BA (1934), then MD (1940) at the Université de Montréal. Neurosurgical training at the Montreal Neurological Institute was completed in1946.

In 1947 Claude Bertrand established the neurosurgical department at Hôpital Nôtre-Dame in Montreal. Very early in his career he was interested in the treatment of involuntary movement disorders and performed anterior choroidal artery ligation on a number of patients, following Irving Cooper's lead. In 1953, he carried out the first stereotactic lesioning (pallidotomy) for Parkinson's disease in Canada.

Although stereotactic frames designed by Speigel and Wycis, Riechert and Leksell were available; they usually required general anesthetic for application and Bertrand was looking for something better. He designed a stereotactic device called a pneumotaxic guide that could be applied under local anesthetic, and was used for his procedures [23] (*Figure 10-6*). Unsatisfied with the inconsistency of lesions produced by cauterization or injection of substances into the brain, he used a leukotome to produce lesions. The original Moniz leukotome with a sharp blade was fairly quickly replaced with a leukotome made with blunt fine piano wire after an intracerebral hemorrhage occurred during one of his procedures [24].

Figure 10-6
Photograph of Claude Bertrand's pneumotaxic guide with lineated prism to avoid parallax while taking preliminary measurements outside the patient's head before control x-ray. Also, on the guiding bar, some of the collars could be angulated to allow penetration at an angle or phantom measurements. (from Neurosurgery 2004, 55(3):699 figure 2)



The foramen of Munro was initially used as the anterior landmark for localization but Bertrand was convinced by Guiot to change to the anterior commissure. Influenced by Riechert's reports [25], Bertrand, like many of his contemporaries moved from the pallidum to the thalamus as the target for Parkinsonian tremor.

Bertrand was joined by Sonis N. Martinez in 1956, Jules Hardy in 1962 and Pedro Molina-Negro in 1967. Jules Hardy had completed his neurosurgical training in 1960 and took advantage of a McLaughlin traveling fellowship to work with

Gerard Guiot and Denise Albe-Fessard in Paris. There they carried out the some of the first microelectrode recordings in Parkinson's patients undergoing stereotactic surgery. Following his return to Montreal in 1962, he introduced these techniques to the group and microelectrode recording was used routinely for their functional neurosurgical procedures [24,26] (*Figure 10-3a*).

Molina-Negro was the neurophysiologist in the group and involved in the analysis of recordings obtained during stereotactic procedures. He suggested using a proportional measurement system to compensate for variations of individual patient anatomy, and they adopted one in which the AC-PC line was divided into ten equal parts. Using this system, a subthalamic, prelemniscal area target could be delineated with such accuracy that the mere introduction of an electrode was sufficient to arrest tremor [27,28].

One of the major contributions to functional neurosurgery coming from this group was the inception and development of the technique of selective peripheral denervation for the treatment of torticollis [48]. They were unhappy with the results of stereotactic thalamic interventions and wondered whether peripheral denervation could improve the results [18]. They noted that significant though temporary improvement could be produced when active muscles were injected with 1% lidocaine under EMG guidance. Their results of combined thalamotomy and peripheral denervation were reported in 1978 [29]. But they ultimately found that peripheral denervation alone was quite effective for treating torticollis.

The Toronto School

The Toronto Neurosurgical program started with Kenneth McKenzie, who broke off from general practice in 1923 to take up a fellowship at the Peter Brent Brigham in Boston. While there he published an article describing sectioning of the anterior cervical spinal nerves along with the spinal accessory for the treatment of torticollis – a procedure we still call the McKenzie procedure in Canada [30]. He returned to Toronto in 1924 as a surgical resident and went on from there to develop neurosurgery at the Toronto General Hospital. After his retirement in 1952, Dr. Harry Botterell took over the program until 1963 when he left to become Dean of Medicine at Queen's University in Kingston. The program was then taken over by Dr. Tom Morley.

Dr. Ron Tasker (*Figure 10-7a, b*) was a trainee of the Toronto Neurosurgical Program, obtaining his Royal College Fellowship in Neurosurgery in 1959. Tasker spent the following year with Clinton Woolsey at the University of Wisconsin's Laboratory of Neurophysiology. Woolsey was studying the evolution of the sensorimotor cortex, and carried out cortical mapping in a variety of animals. Tasker developed a great deal of admiration for the 'simple expressive beauty' of the figurine charts that were used to represent the results of cortical mapping. Additional time was spent at the National Hospital in Queen Square, London (as was the tradition for Neurosurgical trainees at that time) and in Europe observing Albe-Fessard, Guiot, Riechert, Leksell, Talairach and others.

Tasker returned to Toronto September 1961 and started his neurosurgical practice. At that time, functional neurosurgery in Toronto consisted of open cordotomy, the Frazier operation for tic douloureux, open dorsal rhizotomy for pain and the McKenzie operation for torticollis.

At that time, stereotactic surgery was used primarily for the treatment of tremor associated with Parkinson's disease. Pallidotomy was the favored procedure, carried out using ventriculographic guidance and macrostimulation to identify internal capsule. Early on, lesions were made by the inflation of a balloon and instillation of alcohol, or by cryolesioning. Tasker (May 2008, personal communication) rapidly adopted radiofrequency lesioning after its introduction in the early 1960s.

Figure 10-7
(a) Ron Tasker performing stereotactic surgery with one of the earlier Leksell steterotactic frames (b) Tasker (*right*) with Hirotaro Narabayashi from Japan

a b

Tasker followed Riechert's lead in moving the tremor target from pallidum to thalamus sometime in the early 1960s [25].

Tasker espoused the philosophy that the stereotactic operating room offered an opportunity to study the physiology of the brain. He established early collaboration with Raimond Emmers, a physiologist at the College of Physicians and Surgeons of Columbia University and later Leslie Organ of the Department of Physiology at the University of Toronto to study the somatosensory pathways of the thalamus and upper midbrain [31]. A computer program was developed to allow mapping of the stimulation responses using Woolsey-type figurines [32]. In 1982, Tasker et al. [33] published this work – "The Thalamus and Midbrain of Man" – which serves as a remarkable body of data and solid reference material for stereotactic and functional neurosurgeons.

Microelectrode mapping was brought into the operating room sometime in the late 1970s. Dostrovsky and Tasker studied the detailed physiology of the motor and sensory thalamus, mentoring numerous masters and PhD students as well as clinical and research fellows. Between 1964 and 1998, 48 such students and fellows were trained by Tasker, many going on to start up stereotactic programs of their own.

Tasker took the surgical treatment of movement disorders in Toronto from pallidotomy to thalamotomy then through the reintroduction pallidotomy in the early 1990s. Tasker suggested that one of the great oversights in functional neurosurgery was the failure to recognize that pallidotomy was effective for bradykinesia in Parkinson's disease. Deep brain stimulation was introduced in the early 1990s following the work of Benabid in Grenoble.

Tasker (May 2008, personal communication) was interested in the physiology and treatment of chronic pain. When he started practice pain was categorized as benign or malignant, and there were few operations available for the treatment of pain. Cordotomy was one of the favored procedures, was open and performed bilaterally at T1–2. The other procedure was open mesencephalic tractotomy. One of Tasker's most significant contributions to pain management was the recognition of the difference between nociceptive pain and deafferentation or neuropathic pain and the breakdown of neuropathic pain into its different components: steady pain, shooting pain and allodynia [34,35].

Tasker has been honored with numerous awards in recognition of his contributions to functional neurosurgery including: the Spiegel & Wycis Medal, awarded by the WSSFN in 1993; the Distinguished Service Award by the ASSFN in 1995; Award for Distinguished Contributions to Pain Research and Management in Canada by the Canadian Pain society in 1997. The Tasker Chair in Functional Neurosurgery was created at the University of Toronto in 1999.

In the early 1990s Andres Lozano was recruited to the University of Toronto after completing his neurosurgical training at the MNI. Lozano has expanded the functional neurosurgical program in Toronto and has gone on to be a world leader in stereotactic and functional neurosurgery. Lozano now holds the Tasker Chair at the University of Toronto.

Western Canada

Edmonton

Howard H. Hepburn started the Neurosurgical program in Edmonton, Alberta in 1920, having completed his medical training at McGill University in 1910. His plans for neurosurgical training in Germany were interrupted by the outbreak of the first world war. In 1919, he returned to North American and obtained training in neurosurgery at the Mayo Clinic in Rochester.

Hepburn was joined in 1945 by Guy Morton who, ultimately assumed leadership of the Neurosurgical Division with Dr. Hepburn's retirement in 1951. Dr. Thomas Speakman joined the division in 1952. Speakman was trained at the MNI and strongly influenced by Penfield. He started performing stereotactic thalamotomy for Parkinson's disease in the late 1950s [36] and continued until his sudden death in 1969 at the age of 45.

Saskatchewan

Krishna (Kris) Kumar started the functional neurosurgical program in Regina, Saskatchewan in 1961. He came to Canada in 1959 after completing his medical training and surgical residency in Indore, India. He obtained Canadian neurosurgical training under W. D. Stevenson in Halifax and Dr. Morton in Edmonton. In Edmonton, Kumar received training in stereotactic surgery under Dr. Speakman.

At the start of his career Dr. Kumar (May 2008, personal communication) was involved in the stereotactic treatment of movement disorders, mainly thalamotomy for Parkinson's disease. After the introduction of L-dopa and the decline in candidates for movement disorder surgery he concentrated his efforts on the treatment of intractable pain. He was involved in the stereotactic implantation of DBS electrodes in periaqueductal grey (PAG) and sensory thalamus from its start in the late 1960s, and was an advocate of the intravenous pain test for assessing surgical candidacy. This was carried out by injecting small repeated amounts of intravenous morphine to assess the degree of pain relief, and the utilization of naloxone to assess reversibility of the response. Patients responding in a reversible manner to i.v. morphine were considered candidates for PAG stimulation, those not responding were considered better candidates for sensory thalamic stimulation. In general, most patients received simultaneous implantations into both sites followed by percutaneous testing. The most effective electrode was ultimately internalized.

The DBS system at the time consisted of a ring electrode activated by a radiofrequency-coupled stimulator (Medtronic). These systems developed slowly; although approved for the treatment of pain in Canada, DBS for pain never obtained FDA approval in the United States.

Kumar (May 2008, personal communication) was also involved in spinal stimulation for pain. Starting with the open implantation of intradural and interdural electrodes and through to the epidural systems. The initial percutaneous monopolar electrodes came in straight, sigma-shaped and tined varieties. Radiofrequency-coupled systems were eventually supplanted by implanted battery operated systems. Kumar was influential in the development of the fully implantable spinal cord stimulation devices and implantable pumps.

Significant contributions to the area of functional neurosurgery include cost-effectiveness studies for spinal cord stimulation and intrathecal drug therapy [37–39], as well as long-term follow-up studies of SCS and DBS for pain [40–42].

British Columbia

Frank Turnbull was one of the pioneers of neurosurgery in Canada and the first neurosurgeon in British Columbia. He received his neurosurgical training under K. McKenzie in Toronto, followed by postgraduate work at Queen Square in London, and further work with Foerster in Breslau. He started work at the Vancouver General Hospital in 1933 and devoted special attention to the surgical treatment of intractable pain. Turnbull [43–45] attempted to look at pain syndromes as distinct entities so as to better rationalize management. He published on the pain syndromes associated with pelvic carcinoma and specifically looked at the role of cordotomy in the surgical management of these pain syndromes [45]. The early cordotomies were open procedures, carried out at T1–2. In the mid to late 1960s the switch was made to anterior cervical percutaneous cordotomy.

Peter Lehmann joined Frank Turnbull in the late 1940s and started performing thalamotomy for parkinsonian tremor in the late 1950s using the Cooper apparatus and leukotome. Ian Turnbull joined the group in 1966.

Ian Turnbull (July 2008, personal communication) obtained his medical training in Vancouver and neurosurgical training in Toronto. While in Toronto he was exposed to Tasker and his work. Residency was followed by a traveling fellowship in Europe gaining exposure to Leksell, Gillingham and others. After his return to Vancouver he rapidly adopted the Todd Wells stereotactic apparatus and used radiofrequency to carry out thalamotomy for tremor disorders. The stereotactic movement disorder program remained active through to his retirement from clinical practice in 1999. In the early 1990s he, like most neurosurgeons switched to pallidotomy for Parkinson's disease.

Ian Turnbull also established and maintained a large pain practice, initially learning the percutaneous cordotomy technique from his father Frank. He favored stimulation of the ventrobasal thalamus for neuropathic pain [46] and reported on combined thalamic or midbrain lesions with cingulumotomy in some patients with nociceptive pain [46].

The Canadian Stereotactic and Functional Neurosurgery Group

In 2001 the Canadian Neurosurgical Society formed a Section of Stereotactic and Functional Neurosurgery. The Canadian group is small with only 15 or so neurosurgeons carrying out functional stereotactic procedures in the country. As of 2008, there are active programs in Halifax Nova Scotia, Quebec City and Montreal in Quebec, Toronto and London Ontario, Winnipeg Manitoba, Regina Saskatchewan, Calgary and Edmonton Alberta and Vancouver British Columbia.

The relatively small size of the group has been conducive to collaborative work and has resulted in a multicentre study of DBS for cervical dystonia [47]. Other projects are ongoing.

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