The Birth of Human Stereotactic Surgery

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Abstract Stereotactic surgery began with the Horsley–Clarke apparatus which has been used in animal research since 1908. In 1947, Spiegel and Wycis introduced stereotactic surgery in human patients. Their initial choice of target involved the extrapyramidal system, which Russell Meyers had recently performed with craniotomy and manual lesions that might alleviate symptoms of movement disorders, albeit with significant morbidity and mortality, a problem not seen with stereotactic surgery.

Keywords Cartesian coordinates • Extrapyramidal system • Horsley and Clarke stereotaxic apparatus (animal research) • Huntington's chorea • International Society for Research in Stereoencephalotomy•Pallidotomy•Pneumoencephalographic landmarks • Psychosurgery • Russell Meyers • Spiegel and Wycis stereotactic apparatus (human patients) • Stereotaxic surgery • World Society for Stereotactic and Functional Neurosurgery

Animal stereotactic surgery pre-dated human stereotactic surgery by almost 40 years. Why did it take so long to apply this accurate minimally invasive technique to human patients? To find the logical explanation, it is necessary to look at the state of several arts that came together at just the right time — advances in knowledge of physiology of the nervous system, a desire to perform a discredited neurosurgical procedure with accuracy and better patient selection, and advances in radiology that made it possible to identify landmarks in the brain from which accurate target placement could be defined.

The birth of animal stereotactic surgery occurred in 1908, when Horsley and Clarke [1] reported on a device for inserting a needle or electrode accurately into a desired structure in the monkey brain. The animal's head was secured by two ear plugs and by two tabs that held the inferior orbital rims; thus, the ear plugs assured accurate alignment with the midline. The orbital tabs held the head in a reproducibly accurate position. The three planes which formed the Cartesian planes were the midplane, the basal or horizontal plane that passed through the ear plugs and the orbital tabs, and the zero coronal plane that formed right angles to the other two planes and passed through the ear plugs. In the material and methods section of the landmark article, the Horsley and Clarke not only described the stereotactic apparatus but a method to make a stereotactic atlas. The description of forming a reproducible electrolytic lesion in itself was a significant contribution. To conclude on a high note, there was a study of the physiology of the cerebellum of the monkey.

Since localization of the target was dependent on the configuration of structures in the skull, which are consistent within each breed of experimental animals, accurate placement was almost assured. In addition, localization was verified by sectioning the brain when the animal was sacrificed, and data from unsatisfactory placement could be discarded.

It was fortunate that they did not use that type of device on human patients, since they recognized that the human skull is much too variable to assure an accurately placed target. An engineer, Mussen, did, however, design and produce a prototype according to the dimensions of the human head. Fortunately, he did not find a surgeon to use it clinically. The error would have been so great that it might have set back the development of stereotaxis even further.

What were some of the intellectual impediments to the development of human basal ganglia surgery between 1908 and 1940? In 1940, it was thought that surgery on the basal ganglia would cause permanent impairment of consciousness. This was based on assertion by Dandy [2], on observation of two patients, that occlusion of the left anterior cerebral artery and the distribution of the resultant cerebral damage caused permanent loss of consciousness (although his description is

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more like the locked-in state). Consequently, Dandy advocated against basal ganglia surgery or any surgery damaging to the left hemisphere near the corpus callosum [3], since he believed that surgery to the left anterior lobe posterior to the corpus callosum would result in permanent unconsciousness. This truism advocated against basal ganglia surgery, and persisted throughout most of the 1940s.

Bucy [4, 5], a vocal early pioneer in movement disorder surgery, insisted throughout that it was necessary to interrupt the primary motor cortex and its descending tracts to alleviate tremor. The recognized side-effects to those tracts occurred, so the rationale indicated that it was worth trading hemiplegia, spasticity, and contractures for tremor. In the absence of other therapy, either surgical or pharmacological, this was apparently considered a good trade-off. Bucy [6] continued to advocate pyramidal ablation even after successful stereotactic surgery was introduced.

From the practical standpoint, we must note that the majority of patients with movement disorders that were referred to surgeons had Parkinson's disease or sometimes Huntingdon's chorea. There were no effective pharmacological agents, there were a huge number of Parkinsonian patients, many of whom had a history of encephalitis during the epidemics 20 years previously, and tremor was the one sign that could be demonstrated most readily in order to recognize improvement.

Thus, in 1940, we have two giants in the field advocating against the very basal ganglia surgery that later became the basis for stereotactic surgery for movement disorders.

What happened between 1940 and 1947 to change significantly the surgical approach to movement disorders?

The reason that I emphasize 1940 as the comparison date is that we have an excellent snap-shot of knowledge of the basal ganglia at precisely that time. A meeting chaired by Tracy Putnam on "The Diseases of Basal Ganglia" was held in New York under the auspices of the Association for Research in Nervous and Mental Disease on December 20 and 21, 1940. The original proceedings appeared in 1942, but the entire transcripts were re-published by Hafner Publishing Company in New York in 1966, including the discussion of most papers that was heard at the 1940 meeting [7].

The speakers at the 1940 meeting were the giants in their respective fields, whose contributions constituted the state of the art. Speakers included Lewy, Papez, the Ransons, Mettler, Fulton, Merritt, Klemme, and Russell Meyers, (who was not well known at that time), with closing remarks by Putnam. Spiegel was not listed to be in attendance and Wycis was too junior to be invited, although it is certain that they were very aware of the knowledge that was exchanged.

The meeting began with an erudite review of the history of the basal ganglia by Lewy [8], citing its first description by Thomas Willis in 1664, which included a drawing of the sheep basal ganglia by Christopher Wren, the great seventeenth century English architect. That article first used the terms corpus striatum, lentiform bodies and thalamus.

Lewy quoted that the Willis manuscript opined that "the corpus striatum represents an exchange between brain stem and cortex". Lewy quoted Edinger as saying almost 250 years later that "We lack any knowledge of the function of the corpus striatum or of the symptoms following its stimulation or destruction. Lewy also cited his own 1912 manuscript reported that "after one hundred years of laborious preliminary studies the 'Gestalt' of the basal ganglia, their function and diseases became suddenly visible around the year 1912" [9], 4 years after the introduction of the Horsley–Clarke apparatus, but there was still disagreement about the relationship of the basal ganglia as to function and the relationship to motor disorders [8].

Foerster reiterated at the 1940 meeting that the corpus striatum is a center for the integration of elemental movement patterns into hierarchies of automatic associated acts [10].

A few years before the 1940 Meeting, in 1937, Magoun et al. [11] suggested that emotional expression, at least in part, is subtended by the basal ganglia, but gave little emphasis to motor control, as demonstrated by Meyers [12] at the 1940 meeting.

We cannot leave the history of surgical treatment for movement disorders prior to 1940 without acknowledging those procedures that did not involve the basal ganglia, or even the brain. To present a few examples, Foerster suggested posterior rhizotomy for treatment of tremor [13]. Royle reported on sympathectomy as a treatment for movement disorders in 1924 [14]. Puusepp advocated dorsal column section for a variety of movement disorders [15]. Almost any part of the nervous system was attacked in futile attempts to alleviate motor disorders. Even today, we have only little information about many of the motor disorders that do not have an animal model for research; it is common to attempt treatment with interruption or stimulation of a variety of targets, most of which involve the brain stem.

Let us return to the 1940 meeting. Bucy continued to endorse ablation of the motor cortex or pyramidal tract, trading hemiplegia, spasticity, dyspraxia, hyperreflexia, clonus, and spreading reflex synergies for alleviation of motor disorders, especially tremor of Parkinson's disease. He indicated that improvement in motor disease is not possible without involving ablation of the motor cortex or its related tracts [5].

No one considered challenging Dandy's admonition against surgery of the basal ganglia until Russell Meyers [16] spoke. As probably the most junior participant is the discussion, his presentation was scheduled just before the chairman Putnam's final paper, which included a concluding summary of the meeting [7].

Meyers was then an instructor in Neurophysiology and Neurology at the Long Island College of Medicine, as well as Assistant Neurosurgeon at several New York Hospitals,

and he later became Professor of Neurosurgery at the University of Iowa Medical School.

During 1939 and 1940, Meyers [12, 16] performed the first successful extrapyramidal surgery for treatment of unilateral tremor of Parkinsonism. There were eight patients in all; each reported with a complete neurological history, but only one of the patients was treated with sufficient success to advocate the use of brain stem surgery. All patients were operated while awake, as was most common in the neurosurgery of those days. Since there no localizing devices, the plan was to use the ventricular anatomy to visualize what was probably the head of the caudate nucleus. A right frontal craniotomy was performed and the lateral ventricle entered, except in one patient where there was difficulty finding the ventricle with a brain cannula. In the second patient, the improvement was encouraging, but only temporary, so three craniotomies over 4 months were performed with only modest improvement. Other targets were used in the next three patients, with only slight improvement.

In all patients, an attempt was made to extirpate the head or part of the head of the caudate nucleus, but in several, there was also damage to the anterior limb of the internal capsule. The final two patients appeared also to have section of the ansa lenticularis with very good to excellent results, but the seventh patient developed a craniotomy wound infection which proved fatal on the eighth postoperative day.

The eighth patient reported at that meeting was operated on December 3, 1940, just 3 weeks before the meeting. She had section of the ansa lenticularis and some of the lenticular funiculus, so probably the adjacent globus pallidus had also been injured. She was described as having an "excellent result" with no qualifications. It is interesting to note that the first targeted procedure employed by Spiegel and Wycis 7 years later was not a pallidotomy, but a pallido-ansotomy, similar to the lesion made by Meyers' open surgery.

Meyers continued to perform the transventricular approach to the caudate and globus pallidus, and reported 58 patients in proceedings of a subsequent meeting [17]. By that time, stereotactic surgery had been demonstrated, and Meyers opined that the 12 % risk of open surgery was too great to be justified.

What was demonstrated by Meyers' case reports? Success could be achieved without encroaching on the primary motor fibers — *Bucy was wrong*. The patients had no impairment of consciousness after resecting or lesioning a structure within the brain stem — *Dandy was wrong*. The door was opened to the development of human stereotactic surgery.

Another seemingly unrelated milestone occurred between 1940 and 1947. Intraoperative radiology became practical. It was possible to take an X-ray and have the developed film returned to the OR in as little as 10 min. The definition was good enough to identify an air-filled third ventricle, so intracerebral landmarks could be used.

The field of animal stereotaxic surgery as a means of studying neurophysiology advanced steadily from the time of Horsley and Clarke's [1] introduction of the method, but human stereotaxis was not introduced for 39 years afterward. The significant difference between animal and human stereotactic surgery concerned the way landmarks were localized in three-dimensional Cartesian space. The animal headholder not only secured the animal's head in proper alignment, but provided the references to measure the coordinates of the target. Human stereotactic surgery relied on landmarks within the brain, such as the mid-plane, and the anterior and posterior commissures to establish a frame of reference. This distinction was great enough that Spiegel and Wycis originally called this new technique "stereoencephalotomy", that is, using the anatomy of the encephalon to establish the basic coordinates.

The stage was set to introduce human stereotactic surgery.

The first Spiegel–Wycis apparatus was essentially a Horsley–Clarke apparatus mounted on a head ring that was secured to the patient's head by an individually made plaster cap with a hole in the middle. The article appeared in *Science* [18], along with two views of the apparatus.

The original motivation to develop human stereotactic surgery was to perform more refined pre-frontal lobotomy for psychiatric disease, for instance by making a controlled lesion in the dorsomedial nucleus of the thalamus. However, by the time that human stereotaxis appeared, pre-frontal lobotomy had fallen out of favor.

The first procedure was pallido-ansotomy for Huntington's chorea, with good results and no neurological complications. During the first 4 years the mortality rate was less than 1 %, which has fallen to less than 0.5 % thereafter, during which time basal ganglia surgery became the accepted procedure for motor disorders.

Often overlooked is the last paragraph of the 1947 paper in *Science* [18].

"This apparatus is being used for psychosurgery… Lesions have been placed in the region of the medial nucleus of the thalamus (medial thalamotomy)… Further applications of the stereotaxic technique are under study, e.g., interruption of the spinothalamic tract in certain types of pain or phantom limb; production of pallidal lesions in involuntary movements; electrocoagulation of the Gasserian ganglion in trigeminal neuralgia; and withdrawal of fluid from pathological cavities, cystic tumors." Spiegel was especially secretive about ongoing projects, so I am certain that all of those procedures had been done prior to that first publication [18].

One might ask why the first patient had Huntington's chorea rather than Parkinson's disease. Kennard and Fulton had observed paucity of movements in primates after pallidal lesions [19] and Spiegel and Wycis were concerned that pallidotomy might make parkinsonian bradykinesia worse.

It was not until Hassler and Riechert in 1951 demonstrated that a lesion in the ventrolateral thalamus near the site of the pallidofugal fibers could safely and effectively manage Parkinson's disease that thalamotomy was accepted as a target for Parkinson's disease and other movement [20–22].

There were several basal ganglia targets developed during the first few years. Pallidotomy, actually pallidotomy–ansotomy, became the most common target for Parkinson's disease [23, 24]. In 1952 Spiegel and Wycis compared mesencephalotomy, thalamotomy and pallidotomy [25]. In 1963 they reported making a lesion in Forel's field, which they named campotomy, as their favored target for Parkinson's disease [26].

The status of human stereotactic surgery was reviewed in 1952 in a book, *Stereoencephalotomy, Part I*, by Spiegel and Wycis, which included the first human stereotactic atlas [27]. A decade later they wrote *Stereoencephalotomy, Part II* [28], which documented some of the tremendous progress made during the first decade of human stereotactic surgery, progress that is occurring at an ever more rapid rate.

So what happened between 1940 and 1947? Basic anatomy and some physiology of the basal ganglia had advanced. Russell Meyers proved that basal ganglia surgery could be done without impairing consciousness and could be used as a treatment for Parkinson's disease. Intraoperative X-ray was introduced.

The stage was set for human stereotactic surgery to be born.

Conflict of Interest We declare that we have no conflict of interest.

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