3 History of Stereotactic Surgery in US

P. L. Gildenberg

The early use of functional neurosurgery was begun by Horsley [1] in England at the end of the nineteenth century, and the invention of stereotactic surgery in animals was begun by Horsley and Clarke [2] at the beginning of the twentieth century. Human stereotactic surgery began almost at mid-century, i.e., 1947, in the United States by Ernest A. Spiegel and Henry T. Wycis [3] at Temple Medical School in Philadelphia. Stereotactic surgery was accepted at so many institutions so quickly that it is difficult to identify individual "schools" of stereotactic surgery, as it is in other countries. Indeed, in the early 1960s many neurosurgeons, who did not publish, were practicing functional neurosurgery, but most quickly left the field when L-dopa was introduced near the end of that decade [4] and have not returned to the field [5].

In the first half of the twentieth century, prior to the introduction of human stereotaxis, several American functional neurosurgeons were dominant in the use of non-stereotactic techniques for movement disorders.

Paul Bucy, in Chicago, recommended motor cortex extirpation or corticospinal tractotomy for the treatment of athetosis [6] and Parkinson's disease [7]. Bucy [7,8] had declared well into the 1950s that it was necessary to damage the corticospinal system in order to achieve relief from involuntary movements.

Dandy [9], based on observation of several patients with intracerebral hemorrhage, had averred that damaging the extrapyramidal system would result in permanent intractable coma.

Earl Walker, of Johns Hopkins, reported a pedunculotomy wherein he sectioned the lateral two-thirds of the peduncle for relief of hemiballismus [10] or parkinsonian tremor [11]. It was in attempting the Walker procedure that Irving Cooper had his famous "surgical accident," where he accidentally cut the anterior choroidal artery and found the patient much improved, which led him to advocate ligation of that vessel for treatment of movement disorders [12], as discussed below.

The most important but often overlooked American functional neurosurgeon of the pre-stereotactic era is Russell Meyers of the University of Iowa. It was his pioneering work that proved both Paul Bucy and Walter Dandy wrong. In 1939, Meyers [13,14] performed a craniotomy and transventricular approach to resect the head of the caudate nucleus for successful treatment of Parkinsonian tremor. His observations were presented at a meeting of the Research Association for Nervous and Mental Disease the following year [14], where a number of senior members encouraged him to pursue these observations, which led to the publication of results in 39 patients operated with various open surgical procedures of the basal ganglia [15]. The results were good, but the mortality rate was so high that even Meyers recommended against such surgery. His observations, however, were critical to defining the first extrapyramidal targets, significant information that led directly to the first stereotactic surgery for a movement disorder, Huntington's chorea, with the pallidum as the target [3]. Stereotactic surgery produced even better results and brought the mortality rate down to 1% within 3 years of its introduction [16]. In 1963, Meyers resigned his appointment

at the University of Iowa, reportedly for personal reasons, and became Chief of Neurosurgery of the Appalachian Regional Hospital at Williamson, West Virginia. It was not uncommon thereafter for the question to be raised at each Stereotactic Society Meeting, "Whatever happened to Russell Meyers?"

Ernest A. Spiegel (*Figure 3-1*) graduated from the University of Vienna, where he remained on the faculty both as a neurologist and laboratory scientist. As anti-Semitism advanced in Austria during the 1930s, he found himself with fewer students and restricted access to his laboratory. A businessman who observed this on a trip to Vienna related Spiegel's plight to Dr. William Parkinson, the Dean of Temple Medical School, who invited not only Ernest Spiegel but also his wife, Mona Spiegel-Adolph, PhD, Professor of Colloid Chemistry, to join the faculty in Temple, where they both worked until retirement.

Spiegel was small in stature, with wire-rimmed glasses, a somewhat unkempt look, and a thick accent which identified him as a professor steeped in the European academic philosophy. He remembered everything, and as he wrote his manuscripts (usually with a pencil stub on the back of used EEG paper), he inserted the citations without the need to consult his library. His laboratory consisted of two small and cramped rooms – one lined with shelves that contained an uncounted number of cat brains in baby food jars and the other containing a Faraday cage for recording. Inside the cage was an animal stereotaxic apparatus on a small table. Although many considered Spiegel severe because of his professorial look, he had a wry sense of humor, which was a necessary trait to work with Henry T. Wycis, who was a practical joker.

Henry Wycis (*Figure 3-2*) was incorrigible. He came from a middle class family, and helped supplement his living expenses by playing semi-professional baseball during college, which seemed remarkable, because he weighed over 300 pounds by the time I met him. He began to work with Spiegel when he was a medical student – although his academic record was unsurpassed for many years, he also held the record

Figure 3-1
Ernest A. Spiegel

Figure 3-2
Henry T. Wycis

for having missed the most classes, which may have accounted for his time in Spiegel's laboratory. They continued to work together while Wycis was a neurosurgical resident at Temple and after he had joined the faculty. Just the opposite of Spiegel, Henry Wycis loved to be with a diverse group of people. He enjoyed doing card tricks for his friends. It was rumored that he had earned his way through Medical School by successfully playing poker, which may be because of his photographic memory or may explain his love of card tricks.

After stereotactic techniques were introduced in 1947 [3], many neurosurgeons visited Spiegel and Wycis at Temple Medical School in Philadelphia to learn of this new field and return home to make their own apparatus, (since none were commercially available for approximately the next decade,) and become practitioners of this new discipline. Although many of the visitors were from Europe, many were also US neurosurgeons. Even though the field was born in the US, the stereotactic community was and remains truly an international community. Those most active in the field during the 1950s, probably fewer than 30 surgeons, met irregularly at various institutions. The information exchange was informal, open, and enthusiastic, since those scientists shared the excitement of participating in a new science.

The first patient reported by Spiegel and Wycis in 1947 [3] had Huntington's chorea. His involuntary movements became more severe when he was stressed. Consequently, two lesions were made, one in the globus pallidus for the involuntary movement and one in the dorsomedial nucleus of the thalamus to lessen the stress reaction. Lesions were made with alcohol injection, in hopes of sparing the fibers en passage. The next patients had lesions made with a direct current, which had been described in detail in Horsley and Clarke's original animal stereotaxis paper [2]. Spiegel and Wycis concluded their paper by commenting, "the apparatus is being used for psychosurgery... Lesions have been placed in the region of the medial thalamus...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 fluids from pathological cavities, cystic tumors." Spiegel was somewhat secretive about future plans, and I am certain that they had already done those procedures prior to the first publication.

I first met Spiegel and Wycis during my freshman year at Temple Medical School. A new summer research program had been announced, and I was looking for someone in the neurological sciences to be my sponsor and guide my research. I was referred by the head of physiology, since there was no neurophysiologist in that department I walked into Spiegel's laboratory to find him and Wycis reviewing pre- and postoperative 8-mm motion picture films of patients. They invited me to sit and watch, and 2 hours later I was accepted as Spiegel's graduate student. This was in the spring of 1956, just 9 years since the field of stereotactic surgery had begun, when it was still in its infancy. Spiegel and Wycis then performed surgery on only one patient per week. Targeting required a pneumoencephalogram, which was performed with the apparatus in place on Tuesday. The patient was so sick from the study that the surgical part was delayed until Thursday, when the apparatus was re-applied and the procedure done. Every time an electrode was inserted into the brain of an awake patient was an opportunity to study human neurophysiology, which both helped our understanding of the human extrapyramidal nervous system and provided physiologic confirmation that the electrode was at the intended target.

In 1968, the International Society for Research in Stereoencephalotomy was formed, along with the American and European

Branches. The officers of the American Branch, which included both Canada and the United States, included Ernest Spiegel as President, Lyle French as Vice President, and Henry Wycis as Secretary-Treasurer. Claude Bertrand of Montreal was the sole Canadian member of the Board, and served along with Blaine S. Nashold, Jr., Vernon Mark, Robert W. Rand, and Orlando Andy.

At the next official meeting in 1970, those same neurosurgeons remained officers, an indication of how small the membership was, with French as the President, and the non-neurosurgeon Spiegel resigned from his office. At the next meeting in 1972, John Alksne was a new member of the Board, in place of Lyle French.

The organization was revamped in 1973 as the World Society for Stereotactic and Functional Neurosurgery, and the American Society for Stereotactic and Functional Neurosurgery (as well as the European Society) were formed. It was by that time 25 years since the introduction of stereotactic surgery, and each of the founders had taught a number of trainees, so the field had been expanding rapidly. The officers of the American Society retained Blaine Nashold as President and Claude Bertrand as Vice-President. I took over as Secretary shortly after Henry Wycis' death in 1972, and held that position in both the American Society and the World Society for the next 28 years, except for the years I was President of the American Society from 1977 to 1980 and President of the World Society for Stereotactic and Functional Neurosurgery from 1993 to 1997.

The evolution of stereotactic and functional neurosurgery in the United States took a somewhat different course than in most of the rest of the world. Up until the last decade, most stereotactic surgeons performed such surgery as part of a general neurosurgical practice, or one which also featured other subspecialties. There were few "stereotactic centers," even in universities, as was the norm in other countries where medicine was directed by government or academic agencies. Both medical school and private neurosurgical practitioners devoted part of their practice to stereotaxis, but also performed other neurosurgery, as well. This is in contrast to the last decade, where more sophisticated technology requires a team, so that multispecialty stereotactic services are more common, usually centered around teaching programs, such as Pat Kelly at NYU, Ali Rezai at the Cleveland Clinic, and others.

In the pre-dopa days, the largest functional neurosurgical practice in the US was that of Irving Cooper, who devoted his practice to functional neurosurgery after the mid-1950s [17]. He embarked on functional neurosurgery because of a "surgical accident" [12]. He was performing a Walker [11] pedunculotomy for Parkinson's disease, when he accidentally cut the anterior choroidal artery. He aborted the procedure, but the patient awoke with marked improvement. That led Cooper to advocate ligation of that vessel for the treatment of Parkinson's disease [12]. The distribution of that artery, however, is very variable, and so were the results of its ligation. By that time, the pallidum had become a common target for stereotactic treatment of parkinsonism [18], so Cooper advocated injecting alcohol into that structure in so-called chemopallidectomy [19]. Again the results were variable, since the insertion of the needle was free-hand and the alcohol spread in an uncontrolled fashion along the adjacent tracts. He tried using a thicker solution, Etopalin, and a cannula with a balloon at the end in hopes of making a cavity that would contain the injected solution [20]. Neither of these maneuvers produced a more predictable lesion [21,22]. Finally, he recruited a freelance engineer, Arnold StJ. Lee, who designed the cryoprobe, which used a controlled release of liquid nitrogen through a probe to freeze the tissue at the tip [23]. Although it had a large blunt tip that injured tissue on insertion, it produced a predictable lesion at the tip. It was purely coincidence

that the engineer who built the Cryoprobe was the same Lee who is the fourth author on the first stereotactic paper by Spiegel and Wycis [3] in 1947.

Cooper used an aiming device that was not truly stereotactic, in that it was not based on a Cartesian system. He approached the pallidum by inserting a cannula ventral and medial through the temporal lobe. One of his patients, who had an excellent result, was killed in an accident. An autopsy involving the brain showed that the lesion was in the ventrolateral thalamus, a target that had already been described as preferable for tremor. Cooper changed his target to that structure and reported another large series of chemopallidectomy.

Cooper brought functional neurosurgery, including stereotactic surgery, to the public through the mass media. One of his patients was Margaret Bourke-White, the famous Life magazine photographer who suffered from Parkinson's disease. She insisted that her surgery be photographed by one of her colleagues, Alfred Eisenstadt, who was equally famous. Her procedure and result were excellent, and the pictures and article in a mass circulation magazine brought considerable attention to Dr. Cooper and to stereotactic and functional neurosurgery.

There have been persistent stories about clashes between Cooper and Wycis at stereotactic meetings. Some of the more colorful stories had them coming to physical blows. Not only is that not true, as far as I can document, but that competition would have gone to Wycis. He was a bear of a man, who weighed more than 300 pounds, and was a semi-professional athlete in his college years. There certainly were verbal assaults, however, and a sense of one-upmanship when they disagreed. I was present at a stereotactic meeting at Temple Medical School in 1958, when such a competition occurred. Cooper brought one his successful patients to the meeting to show how well he could write on a blackboard after surgery. Not to be outdone, Henry Wycis brought a patient to the meeting the following day to demonstrate how well he played the piano after a pallidotomy. We have lost much of the color of those early meetings.

There has been a recent shift toward implanting deep brain stimulators, but story actually began in the late 1960s. The development of the majority of neuromodulation devices presently used occurred in the United States, mainly through Medtronic®, that remains the dominant supplier of implantable stimulators [24]. The introduction of the gate theory by Melzack and Wall [25] in 1965 led Norm Shealy, a neurosurgeon at Western Reserve Medical School (now Case Western Reserve) in Cleveland, to consider stimulating the dorsal columns of the spinal cord to "close the gate" for relief of chronic pain [26]. He worked with Tom Mortimer, who previously had spent time working at an American company, Medtronic®, that at time had several implantable stimulators on the market. Their Barostat stimulator that was used for stimulation of the carotid nerve for management of hypertension in 1963 and their Angiostat in 1965 to treat angina, were adapted to electrodes designed by Mortimer to stimulate the spinal cord, and the field of neuromodulation using commercially available implantable stimulators was born [24]. Shealy left neurosurgery soon thereafter to become a horse rancher in Wisconsin and write mystery books.

It was in 1973 that Hosobuchi [27], then at the University of California at San Francisco, inserted an electrode into the somatosensory thalamus to treat denervation pain, and deep brain stimulation became a reality. Shortly after that, Don Richardson [28,29], of Tulane in New Orleans, stimulated the periaqueductal area for management of somatic pain. At around the end of the 1970s, the use of deep brain stimulation required approval by the FDA, but only one of the three companies manufacturing implantable stimulators performed the necessary studies to document its benefit in pain; the third company

was Avery, who obtained approval, but their founder, Roger Avery, retired just at that time, so the use of deep brain stimulators was de-approved. The use of deep brain stimulation ceased in the US. It was not until the use of implantable deep brain stimulators for motor control was documented by Alim Benabid [30] and later by Jean Siegfried [31], colleagues in Europe, that there has been a re-ignition of DBS activity in US centers. This led to the re-approval of DBS for movement disorders by the FDA in early 2002.

Lars Leksell [32,33] introduced the Gamma Knife for stereotactic radiosurgery in Stockholm. The first unit installed in the United Staates was guided through the vast regulatory bureaucracy by Dade Lunsford [34] at the University of Pittsburgh, which became one of the most active Gamma Knife centers anywhere. Once the regulatory problems had been addressed by Lunsford, many Gamma Knives were imported into the US, sometimes directed by neurosurgeons who had previously worked in Sweden, such as Ladislau Steiner at the University of Virginia and Georg Noren at Rhode Island Hospital.

Although linear accelerator stereotactic radiosurgery was invented by Leksell [32] in Europe, he used primarily his Gamma Knife. Later Betti [35] and Colombo [36] reintroduced the linac for radiosurgery. Several US neurosurgeons also became active in that time when the benefits of radiosurgery were becoming apparent, but there were few Gamma Knives in this country. Linac systems were developed at the University of Florida at Gainesville by William Friedman and Frank Bova [37]. Several neurosurgeons including Peter Heilbrun were involved in development of the Radionics XKnife, which was first used at the Joint Center in Boston by Jay Loeffler [38]. The use of proton beam therapy was reported by Ray Kjellberg [39] as early as 1962. During the past few years, a Proton Beam Center was opened at Loma Linda and more recently at the MD Anderson Cancer Center in Houston.

Pain management has always been a major interest of US neurosurgeons. An appreciation for the evolving philosophy of neurosurgical management of pain can be obtained by perusing the three volumes co-authored by William Sweet, who was the epitome of professorship. The first was by James White and Sweet [40] in 1955, which emphasized the interruption of the primary pain pathways. The second by those same authors appeared in 1969 [41], and provided a somewhat more conservative approach that included the extralemniscal pathways, as well. The third by Jan Gybles of Belgium and Sweet [42] in 1989 emphasized the complexities of pain perception as a guide to management.

Anterolateral cordotomy was simplified by Sean Mullan [43], who in 1963 reported a technique of lesioning that part of the spinal cord by percutaneous insertion of a strontium needle at the C_{1-2} level for a measured duration. The technique was further modified in 1965 by Hu Rosomoff [44], who used a radiofrequency lesion to interrupt the lateral spinothalamic tract, making it accessible to most neurosurgeons. Paul Lin and I [45,46] introduced a technique that introduce the needle through a lower cervical disk, thus avoiding fibers concerned with respiration. It is more than coincidence that the two neurosurgeons with the largest series of percutaneous cervical cordotomies, Rosomoff and I, came to recommend a very conservative approach to surgery and favored comprehensive multidisciplinary management of chronic pain [47,48]. Both of our programs resembled the comprehensive pain management program pioneered at the University of Washington in Seattle, which was led by the anesthesiologist John Bonica [49], and the neurosurgeon John Loeser [50,51].

Interest in stereotactic and functional neurosurgery has been increasing in the United States, especially since the use of deep brain stimulation for motor disorders became available in 2002. The field is of interest to neurologists

and neurophysiologists, as well as neurosurgeons, which fostered a team approach to management of Parkinson's disease and other movement disorders. This has developed to the point where the use of intraoperative microelectrode recording has become the norm. Not only has the field become more active, but the scientific basis of the diseases and techniques are being studied with increased intensity in order to assure further progress.

Because of the increased complexity and sophistication of electrode implantation, many multidisciplinary centers have developed in the US, such as David Roberts at the Dartmouth-Hitchcosk Medical Center, Michael Kaplitt at Weill Cornell Medical College in New York, Pat Kelly at New York University, Ali Rezai at the Cleveland Clinic, Ray Bakay in Atlanta and then Chicago, then Robert Gross in Atlanta, Michael Schulder in Manhasset, NY, Philip Starr and Nicholas Barbaro at the University of California in San Francisco, Jamie Henderson at Stanford, Tony DeSalles and Mike Apuzzo in Los Angeles, and Kim Burchiel in Portland Oregon, to name but a few.

In 1987 I asked, "Whatever happened to stereotactic surgery?" [5] The answer is, "It is doing well and advancing at an unprecedented rate."

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