Evolution of Movement Disorders Surgery Leading to Contemporary Focused Ultrasound Therapy for Tremor

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KEYWORDS

• Essential tremor • Focused ultrasound • Movement disorders • Pallidotomy • Thalamotomy • Thermography

KEY POINTS

- Historically, patients with tremor of various causes, including essential tremor (ET), parkinsonian rest tremor, and action tremor, have been treated with stimulation or lesions placed in the ventrolateral thalamus.
- The most effective antitremor target in the brain may be the ventrointermedius (Vim) nucleus of the thalamus, a small subnucleus of the ventrolateral thalamus.
- It is now possible to create a lesion in the Vim nucleus using magnetic resonance (MR) imaging–guided high-energy focused ultrasound in a patient who is awake without a skin incision or craniotomy.

HISTORY OF MOVEMENT DISORDERS SURGERY

Gildenberg[1] describes five major epochs in the evolution of modern movement disorders surgery: (1) the prestereotactic era before 1947, (2) the early stereotactic revolution between 1947 and 1969, (3) the latent period after the introduction of levodopa in the 1970s and 1980s, (4) the stereotactic revival of ablative surgery in the 1990s, and (5) the current modern period of deep brain stimulation. At present, with the advent of high-energy transcranial focused ultrasound, movement disorders surgery may be about to enter a sixth epoch. This article

The authors have nothing to disclose.

Dedication: This article is dedicated to the memory of Ferenc A. Jolesz, MD, the B. Leonard Holman Professor of Radiology, Department of Radiology, Harvard Medical School.

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traces the historical progression of movement disorders surgery from early open craniotomy to the so-called incisionless image-guided ultrasound surgery that is now being developed to treat ET. It also describes relevant history of focused ultrasound and a few general principles that have allowed neurosurgeons to treat intractable tremor with acoustic ablation.

The Prestereotactic Era

An early experimental understanding of motor systems began in the late 1800s, when Fritsch and Hitzig[2] conducted the first investigations into mammalian motor circuitry by applying local electrical stimulation to the cortical surface in dogs. Based on this pioneering work, Horsley, in 1909, resected a portion of the contralateral precentral gyrus in a 15-year-old boy for the treatment of postcarlatina hemiathetosis but acknowledged in later reports that these procedures often resulted in severe paralysis and paresis.[3,4] Hoping to alleviate tremor without weakness, Horsley and Clarke[3] attempted to target specific structures outside primary motor centers, for example, the deep cerebellar nuclei and other subcortical structures. They used the first skull-mounted stereotactic frame using external landmarks to guide slender probes and initiated the first use of discrete electrolytic lesions. The goal of these elegant preclinical investigations in the monkey was to find areas in the brain where small lesions could be accurately placed to control unwanted movements but not abolish movement altogether. This pioneering work in intracranial stereotaxy had to wait until the 1940s to finally be applied to human surgery (see later discussion).

Although Horsley and Clarke[3] laid the groundwork for an understanding of nonprimary motor areas in the brain, other investigators were beginning to study extracranial approaches to abnormal movements. As early as 1908, Foerster[5] reported posterior rhizotomy for control of spasticity and rigidity, leading others to try sympathetic ramisection and various ganglionectomies for similar indications throughout the 1920s and 1930s.[6,7] During this same period, surgical interest in open craniotomy for ablation of primary cortical structures continued despite permanent loss of function and high mortality. For example, Bucy and colleagues[8–10] continued to report their series treating athetosis and parkinsonism with ablation of both the supplementary and primary motor cortices despite accruing evidence from Meyers[11–13] and others that lesions confined strictly to the extrapyramidal system controlled tremor without weakness. Meyers reported excellent tremor control in a patient with hemiparkinsonism by resection of the contralateral caudate head through a transventricular approach, confirming that the basal ganglia is a viable extrapyramidal target for tremor. For other patients, Meyers also explored sectioning of the anterior internal capsule, ansa lenticularis (ansotomy), and internal pallidum. Despite the success of these transventricular extrapyramidal operations, postoperative mortality was never reduced less than 10%, deterring others from adopting similar free-hand transventricular approaches.[14] Nevertheless, Meyers' contributions clearly showed that basal ganglia lesions could effectively treat tremor without causing paralysis or coma. These decisive observations set the stage for future stereotactic surgical methods in targeting extrapyramidal subcortical structures for the treatment of refractory movement disorders.[14,15]

The Early Stereotactic Revolution

It was not until after 1947, when Spiegel and colleagues[16] described a procedure to ablate discrete targets in the human brain using a modification of the Horsley-Clarke frame, that the era of stereotactic surgery clinically emerged. The major advantage of their approach was the use of indirect internal landmarks based on ventricular encephalography to identify particular sites in the brain, making it possible to introduce a probe through a small burr hole to the intended target without the need for direct open visualization. The first stereotactic operation was for the treatment of Huntington chorea in which alcohol injections were made into the pallidum and dorsomedian nucleus. Frame-based stereotaxy opened new doors for further exploration of other subcortical targets and ushered in a remarkably innovative period during which a variety of lesioning methods were explored, including chemical, cryo, thermal, physical, and ionizing energy methods.[17] Stereotaxy improved surgical safety, dramatically reducing the 10% to 15% mortality rates previously reported for open approaches to less than 1% by 1950.[18]

Target discovery was the major development of movement disorder surgery during this early exploratory period, and stereotactians focused predominantly on alleviating tremor and rigidity associated with Parkinson's disease. Based on Meyers' observations, several groups in the United States developed operations that lesioned the pallidum and/or its associated efferent tracts.[19–21] Other groups working in France[22,23] and Germany[24,25] found that lesion of the motor thalamus, the downstream target of the pallidum, produced complete arrest for virtually any type of tremor,