# Lesion Procedures in Psychiatric Neurosurgery

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**Key words**
- Major depression
- Neurosurgery
- Obsessive-compulsive disorder
- Stereotactic
- Surgery

**Abbreviations and Acronyms**
**BD**: Bipolar disorder
**CGI**: Clinical Global Improvement
**CGPSS**: Current Global Psychiatric Social Status Scale
**CSTC**: Corticostriatal-thalamocortical
**DBS**: Deep brain stimulation
**MDD**: Major depressive disorder
**MRI**: Magnetic resonance imaging
**OCD**: Obsessive-compulsive disorder
**YBOCS**: Yale-Brown Obsessive Compulsive Scale

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OBJECTIVE: **Lesion procedures for psychiatric indications have a history that spans more than a century. This review provides a brief history of psychiatric surgery and addresses the most recent literature on lesion surgery for the treatment of anxiety and mood disorders.**

METHODS: **Relevant data described in publications from the early 1900s through the modern era regarding lesion procedures for psychiatric indications, both historical and current use, are reported.**

RESULTS: **The early procedures of Burkhardt, Moniz, and Freeman are reviewed, followed by descriptions of the more refined techniques of Leksell, Knight, Foltz, White, and Kelly. The application of lesion procedures to obsessive-compulsive disorder, mood disorders, and addiction are discussed.**

CONCLUSIONS: **Lesioning procedures have informed modern deep brain stimulation targets. Recent lesioning studies demonstrate the efficacy and durability of these procedures in severely disabled patients. Judicious application of these techniques should continue for appropriately selected patients with severe, refractory psychiatric disorders.**

## BRIEF HISTORY

The late eighteenth and nineteenth centuries witnessed the development of functional neuroanatomy—the concept that specific areas of the brain subserve particular functions. Gall (19) ascribed functional significance to individual units of the brain that he called mental organs. His theory of phrenology ultimately lost favor, but he was nonetheless a pioneer of the concept of localization of brain function. One of his detractors, Flourens (18), performed careful experiments that began to demonstrate the functions of the cerebral hemispheres, cerebellum, and brainstem. Broca (8) and Wernicke (70) further refined localization, especially for language function.

This increasing understanding of functional neuroanatomy led the Swiss psychiatrist Burckhardt to postulate that removing regions of cortex could specifically alter behavior (**Figure 1**) (46). His operations on six patients with psychiatric diagnoses in 1888 likely represent the first modern example of psychiatric neurosurgery. His results from these initial attempts were modest: one patient died after developing status epilepticus, one improved but then subsequently committed suicide, two remained stable, and two became more subdued.

In 1910, the Estonian neurosurgeon Puusepp reported results on 17 patients who underwent a frontal leukotomy-like procedure for manic-depressive disorder or epilepsy (43). Results from the initial four patients were poor; however, in the remaining patients, improvement and reduced aggression were seen (57).

In 1935, Fulton presented a landmark study in primate neurophysiology that would guide the direction of psychosurgery for the next 2 decades. Fulton and Jacobsen trained two chimpanzees to perform some basic behaviors. They noted that under certain conditions when reward was omitted, the animals would have clear emotional tantrums. Each animal then underwent a unilateral frontal lobectomy. Fulton and Jacobsen noted that there was no apparent change in their overall cognitive or emotional capacities. However, when the contralateral frontal lobe was also removed, they noticed marked changes in their emotional faculty without any gross changes in overall cognition. Specifically, they stopped responding to the omission of rewards. Fulton and Jacobsen presented their findings at the Second World Congress of Neurology in 1935. At this meeting, the Portuguese neurologist Moniz proposed ablation of frontal cortex for treatment of psychiatric disease in humans (25, 47).

Moniz enlisted the help of the Portuguese neurosurgeon Lima. In 1935, they performed a prefrontal leukotomy on a 63-year-old woman with anxiety, delusions, and melancholia. They injected alcohol into white matter tracts within the frontal lobes to sever connections responsible for the mental illness. The patient was considered to be cured, despite requiring continuous hospitalization (2). By 1936, Moniz and Lima introduced a new instrument called the leukotome, which consisted of a rod that had a retractable wire loop that could be inserted and rotated to sever white matter connec-

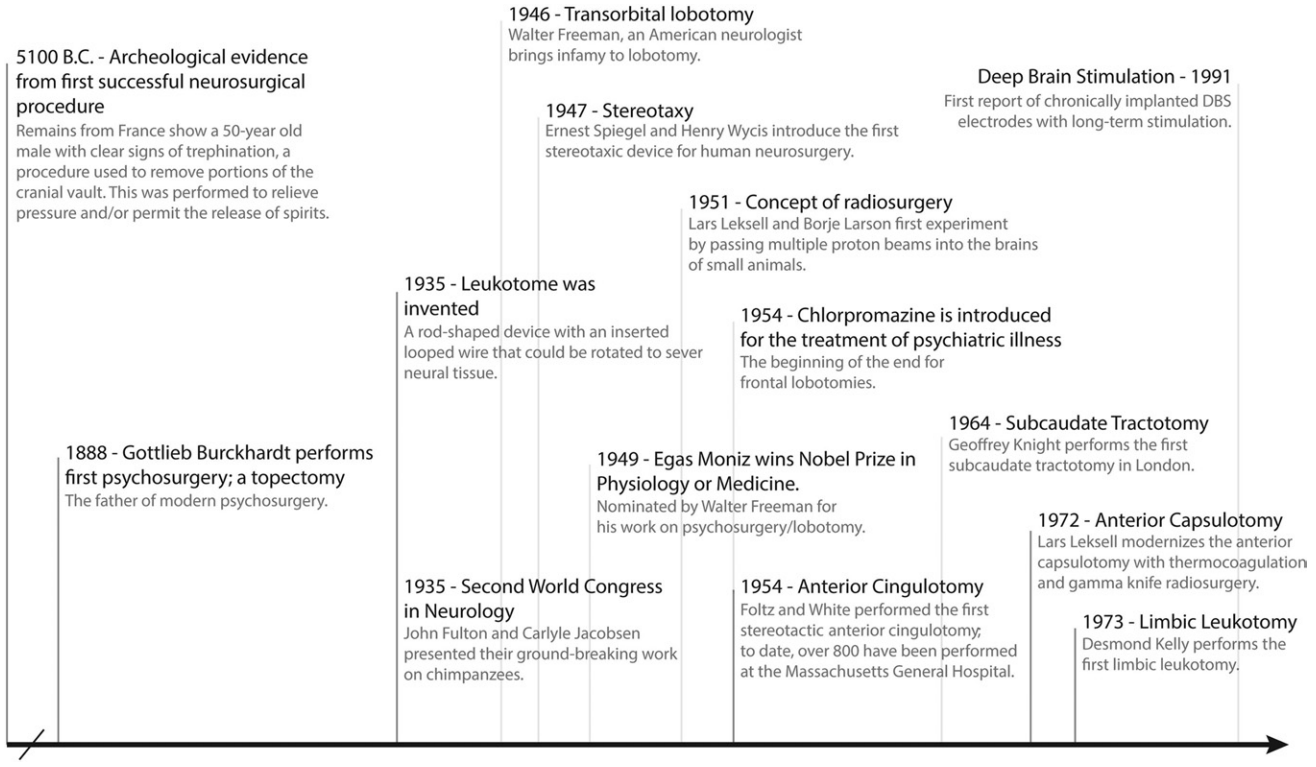


**Figure 1.** Timeline of major events in the history of psychosurgery.

tions. The procedure was done bilaterally with approximately six 10-mm circular lesions per side. Over the next 2 years, Moniz published numerous articles and books on the procedure, and he won the Nobel Prize in Medicine or Physiology in 1949.

Concurrent to Moniz's work, in 1936, the American neurologist Freeman and neurosurgeon Watts began exploring prefrontal lobotomy as a treatment for psychiatric illness. At the time, psychiatric illness was a staggering problem in the United States, with an estimated 400,000 psychiatric inpatients and an annual cost of $1.5 billion (47). In an effort to make the procedure more widely available, Freeman and Watts introduced the transorbital leukotomy in 1946. The procedure did not require an operating room and was originally performed in Freeman's office. An icepick-like tool, called an orbitoclast, was inserted above the eyelid and driven through the orbital roof with a mallet. Sweeping motions were made with the orbitoclast in the desired plane to severe white matter tracts. The procedure was done bilaterally. An estimated 60,000 procedures were performed from 1936–1956 (2). However, increasingly indiscriminate use of the procedure, an accumulating tally of complications, and the development of the first neuroleptics such as chlorpromazine eventually brought an end to the frontal lobotomy era (17).

The development of stereotactic procedures by Tailarach and Leksell in the late 1940s (42) allowed the creation of smaller, more precisely targeted lesions, resulting in improved outcomes and reduced complications. Stereotactic ablation procedures that were developed over the next 2 decades are still in use today to treat patients with severe disease that is refractory to conventional pharmacologic and behavioral therapy. Modern practice of psychiatric neurosurgery must take careful account of ethical objections raised against the notorious transorbital frontal lobotomies of the middle decades of the 20th century. The ensuing public backlash led to the convening of a U.S. Congressional Commission in the late 1970s to investigate the appropriate selection and treatment of patients for these procedures. Their report formed the basis for guidelines governing the practice of psychiatric neurosurgery (12, 69).

At the present time, psychiatric neurosurgery procedures are most often performed to treat severe, refractory anxiety disorders such as obsessive-compulsive disorder (OCD) and mood disorders such as bipolar disorder (BD) and major depressive disorder (MDD) (**Table 1**). We briefly describe these conditions and outline the ablative procedures available to treat them. In addition, we discuss treatment of addiction, both historically and more recent international efforts.

## OBSESSIVE-COMPULSIVE DISORDER

### Description

OCD is an anxiety disorder characterized by persistent unwanted thoughts (obsessions) and ritualistic behaviors or mental acts (compulsions). The intrusive nature of obsessions is a source of overwhelming anxiety and often requires repetitive performance of time-consuming or socially inappropriate behaviors to subdue. OCD is generally considered to be a chronic illness with a lifetime prevalence of 2%–3% in the United States (32, 58). The current standard

**Table 1.** Lesion Procedures

| Procedure | Indications | Method | Target | Side Effects | Efficacy |
|---|---|---|---|---|---|
| Anterior capsulotomy | OCD | Thermocoagulation, Gamma Knife | Anterior limb of internal capsule | Short-term: headache, confusion, incontinence | OCD: 35% reduction in YBOCS |
| | | | | Long-term: weight gain, fatigue, memory loss, incontinence, seizure | |
| Anterior cingulotomy | OCD, MDD, BD | Electrocoagulation | Anterior cingulate | No long-term side effects, low risk for infection | OCD: 32%–48% reduction in YBOCS |
| | | | | | MDD: 60% responders |
| | | | | | BD: 77% improved |
| Subcaudate tractotomy | OCD, MDD, BD, anxiety | Yttrium-90 rods with electrocoagulation, Gamma Knife | Substantia innominata | Short-term: edema, disorientation | OCD: 50% improved |
| | | | | Long-term: seizure | MDD: 32% improved |
| Limbic leukotomy | OCD, MDD, BD | Mechanical disruption, heat, radioactive materials, radiofrequency thermocoagulation | Anterior cingulate, substantia innominata | Short-term: headache, confusion, lethargy, perseveration, incontinence, somnolence, apathy, seizure | OCD: 38%–98% improvement |
| | | | | | MDD: 33% symptom-free, 22% improved |
| | | | | | BD: 68% improved by CGPSS |

OCD, obsessive-compulsive disorder; YBOCS, Yale-Brown Obsessive Compulsive Scale; MDD, major depressive disorder; BD, bipolar disorder; CGPSS, Current Global Psychiatric Social Status Scale.

of care consists of cognitive behavioral therapy and selective serotonin reuptake inhibitors (28). Although meta-analytic studies have shown both classes of treatment to be effective (16, 40), 20%–40% of patients are thought to remain refractory and are chronically impaired (56, 58).

### Neurobiology

The pathophysiologic basis of OCD appears to involve abnormalities in corticostriatal-thalamocortical (CSTC) circuits, specifically orbital-frontal and anterior cingulate cortex (63, 68). CSTC circuits are known to be anatomically and functionally segregated and subserve a wide range of physiologic functions (1). Dysfunction to these information streams is thought to underlie the neurobiologic basis of OCD (52).

Imaging studies have elucidated much of what we know about the pathophysiologic basis of OCD. Structural imaging studies have found differences in gray matter volumes of CSTC regions in patients with OCD versus controls (29, 61). Hyperactivity in CSTC circuits is commonly reported in patients with OCD at rest in functional imaging studies, and this activity is amplified during provocation of OCD symptoms (48, 59, 64). Diffusion tensor imaging revealed abnormalities in anatomic connectivity within the cingulum bundle and the anterior limb of the internal capsule in patients with OCD (9).

## MOOD DISORDERS

### Description

MDD and BD are mood disorders that are among the most common psychiatric diagnoses. During their lifetime, 20% of women and 12% of men are expected to have a major depressive episode. BD is less common, with a lifetime prevalence of 2%–4% (44). Conventional treatment at the present time consists of psychopharmacology including selective serotonin reuptake inhibitors and monoamine oxidase inhibitors, psychotherapy, and electroconvulsive therapy. BD treatments include mood stabilizers such as lithium, carbamazepine, and valproate. However, 20% of patients are refractory to conventional therapy. Ablative surgical procedures for depression have been employed since the 1930s and refined by the advent of stereotaxy in the 1940s and 1950s (3).

### Neurobiology

The pathophysiology underlying both MDD and BD appears to involve abnormalities in medial and orbital prefrontal cortex, limbic circuits regulating emotion, and thalamic and basal ganglia networks (54). Dysregulation of neurotransmitters, including serotonin and dopamine, plays an important role as well.

Positron emission tomography and functional magnetic resonance imaging (MRI) studies have demonstrated altered cerebral blood flow and metabolic activity in prefrontal cortex of depressed patients compared with healthy subjects. Primate studies suggest that the orbital prefrontal cortex plays a role in updating the value of object representations, whereas medial frontal cortex updates the value of action representations. These roles are reflected in difficulty valuing objects and actions, presenting clinically in patients with MDD as anhedonia, abulia, and lack of motivation (44, 54).

## ADDICTION

Epidemiologic studies of substance abuse and dependence reveal 2% of adults in U.S. households had a drug use disorder within the previous 12 months, with 10.4% reporting a drug use disorder during their lifetime (65). Drug use disorders lead to significant disability and inability to fulfill work, school, and home obligations. Current treatment centers on residential or outpatient behavioral therapies combined with pharmacologic therapies to manage withdrawal and control cravings. However, relapse rates remain exceedingly high despite treatment. A large randomized study of combined behavioral and pharmacologic treatment for alcohol abuse demonstrated good clinical outcome, defined as abstinence to moderate drinking without significant psychosocial problems, in half of pa-

tients undergoing therapy, with lower outcome rates for isolated behavioral or pharmacologic treatments (4). Interest in applying psychiatric neurosurgery to substance abuse was based on observations of patients with comorbid depression and substance abuse.

In 1969, Knight (38) reported his results with leucotomy in five heroin addicts, demonstrating reduced withdrawal symptoms and cravings and improved rehabilitation. No patients relapsed in the 6-month follow-up period. In 1978, Dieckmann and Schneider (14) published their experience with hypothalamotomy for addiction. Leucotomy was thought to influence addiction via treatment of underlying mood disorders, and it was believed that hypothalamotomy would directly affect relapse behaviors. Unilateral or bilateral lesioning of the ventromedial nucleus of the hypothalamus was performed in 15 patients. All patients reported increased self-control but also increased appetite and reduced sexual drive. In patients with bilateral lesions, four of six had severe side effects, including lack of impulse, amnesia, vision disorders, and vegetative crisis. Bilateral hypothalamotomy was essentially abandoned.

Stereotactic anterior cingulotomy was evaluated in the 1970s as a treatment of addiction. Kanaka and Balasubramaniam (31) reported on 73 patients with morphine, pethidine, or alcohol addiction who underwent surgery. Patients were followed for up to 6 years, with a relapse rate of 22% without significant psychological deficits or procedural complications. More recently, Russian neurosurgeons reported results of cryocingulotomy in patients with heroin addiction. Bilateral lesions were created in 335 patients; 30% experienced immediate total remission, and an additional 30% were in remission after 2 months. The follow-up period was unreported. However, the Russian government ordered a halt to surgeries for lack of evidence in 2002 (49, 55).

In 2003, Gao et al. (20) published results of ablating the nucleus accumbens bilaterally. The goal was to disrupt the mesocorticolimbic dopamine circuit, which was implicated in psychological dependence in animal studies (35). Lesioning was performed in 28 heroin addicts who were followed for 15 months. Complete remission was reported in 7 patients, and an additional 10 patients relapsed within 6 months but did have an improvement in withdrawal symptoms. Two patients had personality changes, and four had temporary memory loss. However, the study was severely limited by poorly defined assessment instruments, unblinded evaluators, and no comparison with standard effective treatment for opioid dependence. The Chinese government halted surgeries in 2004 (45, 67). In 2010, Wu et al. (72) reported results of stereotactic ablation of the nucleus accumbens in patients with alcohol dependence. Bilateral lesioning was performed in 12 patients meeting criteria for alcohol dependence with repeated relapses despite treatment. Patients were followed for a mean of 16.6 months. Relapse rate by the first year postoperatively was 25%. One patient had temporary hyposmia; no other procedural complications were seen. Severity of alcohol dependence and alcohol cravings, as determined by a standard severity of alcohol dependence scale and frequency and duration of alcohol use, was decreased in the study group compared with preoperative baseline. Given these encouraging results, the authors suggested that stereotactic surgery to treat alcohol dependence is safe and effective, although greater sample size and longer follow-up studies would provide further evidence of efficacy and safety. The authors commented that nondestructive procedures are likely to replace the lesioning used in the study; however, the high cost of implanted stimulation devices may limit their adoption (72).

## LESIONING PROCEDURES

### Anterior Capsulotomy

Developed in the 1940s by Leksell and Talairach, anterior capsulotomy targets the anterior limb of the internal capsule, just superior to the ventral striatum (**Figure 2**) (22). The goal of the procedure is to interrupt fibers connecting the orbital frontal cortex with thalamic nuclei and the caudate. Originally, bilateral lesions were placed using thermocoagulation through burr holes in the skull, resulting in roughly 4-mm-wide lesions. More recently, capsulotomy has been performed using the Leksell Gamma Knife, stereotactically focusing ionizing radiation onto the target site. Although it is a relatively new procedure, efficacy is similar to thermocoagulation, and the need for open surgery is eliminated.

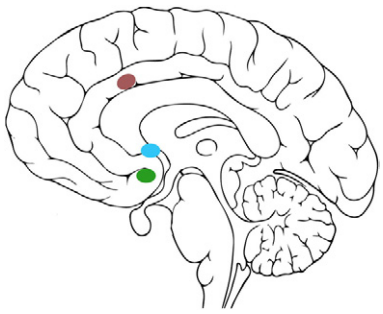

**Figure 2.** Psychosurgical lesion targets. For cingulotomy, two of three magnetic resonance imaging–guided lesions are placed bilaterally in the anterior cingulate (*red*) using thermocoagulation to interrupt fibers from the cingulate to the limbic system. For capsulotomy, bilateral lesions are placed in the anterior limb of the internal capsule (*blue*) using either thermocoagulation or ionizing radiation to interrupt fibers from the orbital frontal cortex to thalamic and basal ganglia targets. For subcaudate tractotomy, bilateral lesions are placed in the substantia innominata (*green*; inferior to the head of the caudate) using radioactive rods to interrupt fibers between the orbital frontal cortex and subcortical limbic targets. For limbic leukotomy, anterior cingulotomy (*red*) and subcaudate tractotomy (*green*) lesion targets are combined.

A controlled study of Gamma Knife capsulotomy for OCD is currently in progress at the University of Sao Paulo, Brazil.

In the 1950s, Leksell performed anterior capsulotomy on 116 patients and reported favorable results; 50% improvement occurred in patients with OCD. More recent outcome studies of capsulotomy for intractable OCD report an approximate 70% improvement (26, 41, 50). Short-term side effects include headache, confusion, and incontinence. Weight gain, fatigue, memory loss, incontinence, and seizure have been reported as rare but more lasting side effects (17). Therapeutic responses for Gamma Knife capsulotomy (>35% improvement in Yale-Brown Obsessive Compulsive Scale [YBOCS] at follow-up) have been reported in 60% of patients with OCD (23), and no significant difference between thermocoagulation and radiosurgery has been reported (62). Serious side effects of radiosurgery include radiation-induced edema and delayed cyst formation (23).

### Anterior Cingulotomy

The earliest reports of cingulotomies date back to the 1940s by Freeman and Watts. It

was noted that patients with comorbid anxiety conditions had the best outcomes. Cairns began targeting the anterior cingulum in 1948 for anxiety, intractable pain, and mood disorders. At the present time, anterior cingulotomy remains the most common neurosurgical procedure for refractory OCD.

The anterior cingulate gyrus has projections into hippocampus, amygdala, periaqueductal gray matter, ventral striatum, and orbitofrontal and anterior insular cortices. Functionally, it is involved in conditioned emotional learning and assigning emotional valence to stimuli (13). Two or three MRI-guided lesions of approximately 1.0 $cm^3$ are made bilaterally in the anterior cingulate (Brodmann areas 24 and 32) by thermocoagulation (**Figure 2**). The goal of this procedure is to interrupt fiber tracts in the anterior cingulate that carry information from the cingulate cortex to the orbital frontal cortex and limbic system.

Ballantine published results of 69 patients who underwent bilateral stereotactic cingulotomy during 1962–1966. Lesions were created using monopolar radiofrequency electrocoagulation with needles placed 3–4 cm from the tip of frontal horns to within 5 mm of the midline to destroy the medial portion of the cingulum. Of patients, 26 had manic-depressive symptoms consistent with a modern diagnosis of BD. In 20 patients (77%), significant improvement occurred as a result of surgery; these 20 patients were followed for 3 months up to 4 years. There were no deaths or major complications attributed to surgery, although three patients (4%) experienced postoperative seizures (6).

In 1987, the safety and efficacy of anterior cingulotomies for a range of psychiatric disorders were first characterized (5). Using a subjective functional/symptomatic rating scale, a 56% improvement for patients with OCD was reported. In 2000, Cosgrove (11) reanalyzed these data with more rigid criteria and found a 33% improvement from cingulotomies.

MRI-guided cingulotomy results from Massachusetts General Hospital from 1991–1995 were reported by Spangler et al. in 1996 (66). Patients were followed for 6–38 months (mean 17 months), and outcome was assessed via the Clinical Global Improvement (CGI) scale and the Current Global Psychiatric Social Status Scale (CGPSS). Patients were considered responders if they improved on the CGI scale and were no longer institutionalized and usually working to some extent (CGPSS score $\geq$3). Partial responders were minimally improved or better on the CGI scale or showed at least some improvement while still requiring intensive care or institutionalization on CGPSS (score $\geq$2). Of 34 patients in the series, 10 had MDD, and 5 had BD. Of the patients with MDD, 60% were characterized as responders, 10% were characterized as possible responders, and 30% were characterized as nonresponders. Of the five patients with BD, two (40%) were responders, two (40%) were possible responders, and one (20%) was a nonresponder. The authors stated cingulotomy is associated with mild, transient side effects and reported no major long-term complications (66).

More recently, long-term prospective studies found a 32%–48% reduction in baseline YBOCS scores after cingulotomies (15, 30). Cingulotomies have a relatively low rate of side effects. A report on the safety of >800 cingulotomies performed at the Massachusetts General Hospital over a 40-year period showed no deaths and only two infections (12).

## Subcaudate Tractotomy

Subcaudate tractotomies were first performed by Knight in 1964 (37). The rationale was to interrupt white matter tracts connecting the orbital frontal cortex and subcortical limbic structures by targeting the substantia innominata (just inferior to the head of the caudate nucleus) (**Figure 2**) (36). Knight focused on the last 2 cm of the lesion created by orbital undercutting, where it entered the subcaudate region. This selective cortical undercutting led to improved results (37), although freehand procedures often led to suboptimal lesion localization. The addition of stereotaxy enabled standardized lesion localization and was termed stereotactic subcaudate tractotomy. Knight used McCaul's stereotactic device to insert rods of radioactive yttrium-90 bilaterally into the white matter just below and anterior to the caudate. $\beta$-radiation emitted from the rods destroyed white matter 2 mm from the surface of the rod. A more recent revision to this procedure replaces yttrium-90 rods with thermocontrolled high-frequency electrocoagulation, with lesions stereotactically created via Leksell frame localization in a manner mimicking the size and location of lesions created by the yttrium-90 rods.

In 1975, Goktepe et al. (21) reported on 208 patients with a mean follow-up period of 2.5 years; using a categorical outcome scale, they found a 50% improvement in patients with OCD after subcaudate tractotomies. Since 1970, the Brook General Hospital in London has performed >1300 subcaudate tractotomies for affective disorders (unipolar or bipolar), OCD, and chronic anxiety (7). Using global clinical categorical and symptom rating scales, they reported 40%–60% of patients led normal or near-normal lives after 1-year postsurgical assessments. Similar to cingulotomies, subcaudate tractotomies are relatively free of major complications. Edema-induced disorientation is observed in approximately 10% of patients postoperatively and may last 1 month. Seizures are the most common long-term complication and are seen in only about 1.6% of patients. Knight (39) reported only one death from >1300 cases examined. More recently, there has been a case report of one patient with OCD improving after a frameless stereotactic subcaudate tractotomy (71).

Hodgkiss et al. (27) reported results of stereotactic subcaudate tractotomy in 286 patients treated from 1979–1991 at the Geoffrey Knight National Unit for Affective Disorders in London. Diagnostic and follow-up data were available on 249 patients; 183 of these patients had a diagnosis of depression. Outcome was assessed 12 months after surgery and categorized as recovered (no symptoms, no additional treatment), well (mild residual symptoms, little to no interference with everyday life, may require medication), improved (significant residual symptoms), unchanged, and worse. For patients with depression, 64 (34%) were recovered or well, 58 (32%) were improved, and 57 (31%) were unchanged or worse. The study did not disclose detailed complications; however, five patients (3%) in the depression group died within the 12-month follow-up period.

## Limbic Leukotomy

In 1973, Kelly et al. (33) reported a novel stereotactic surgical approach focusing on discrete lesions disrupting connections to the limbic system. Targets included the

lower medial quadrant of the frontal lobe to interrupt frontolimbic connections and the cingulum bundle running above the corpus callosum to interrupt the Papez circuit (**Figure 2**). Lesions around 8 mm in size were produced with wire loops, blunt instruments, heat, or radioactive materials. Postoperatively, patients were confused and drowsy for the initial 24–48 hours and then slowly recovered and returned to psychiatric care.

Kelly et al. (33) assessed 66 patients in 1973 with a mean follow-up of 16 months after surgery; using a 5-point clinical rating scale, they reported an 89% improvement in patients with OCD. In 1993, Hay et al. (24) reported an improvement in 38% of their 26 patients after surgery. In 2002, Kim et al. (34) reported a decrease in mean YBOCS scores from 34 to 3 in 12 patients who underwent limbic leukotomy for OCD; at 45 months after surgeon, 10 of the 12 patients returned to previously normal state of function. In 2008, Cho et al. (10) reported a 7-year study of 18 patients who underwent limbic leukotomy for intractable affective disorders. They reported significant improvements according to rating scales in depression (Hamilton Depression Rating Scale), anxiety (Hamilton Anxiety Rating Scale), and negative symptoms (Negative Symptom Rating Scale). Short-term side effects included headache, confusion, lethargy, and perseveration (23).

Mitchell-Heggs et al. (51) reported their results of 66 patients followed for 16 months postoperatively. There were nine patients with depression, all of whom were improved at 6 weeks; however, at 16 months, three (33%) were symptom-free, two (22%) had minimal residual symptoms, two (22%) were improved with significant residual symptoms, and two (22%) were unchanged. The authors commented on 100 patients who underwent the procedure as of publication date and reported only one serious complication, postoperative memory deficit. Transient confusion, headache, incontinence, and lethargy resolved within a few weeks of surgery.

Montoya et al. (53) reported results of 21 patients who underwent MRI-guided stereotactic limbic leukotomy at Massachusetts General Hospital from 1993–1999. Mean follow-up time was 26 months. Six patients (29%) were diagnosed with refractory depression. Four patients had previously undergone bilateral anterior cingulotomy as well as a second surgery to expand these lesions. Lesions were created with radiofrequency thermoablation. Targets were just inferior to the head of the caudate nucleus and the anterior cingulate gyrus, approximately 2 cm posterior to the tips of the frontal horns. Three patients (50%) were considered responders to surgery according to physician-rated assessments of global functioning. One patient committed suicide postoperatively. Among 21 patients, complications included wound infection in 1 patient, persistent complex partial seizures in 1 patient, short-term memory disorder in 2 patients, and persistent headaches in 1 patient; minor transient postoperative symptoms included somnolence (6 patients; 29%), apathy (5 patients; 24%), and seizure (3 patients; 14%).

Limbic leukotomy performed to treat BD in 16 patients in Taiwan was reported. Radiofrequency thermocoagulation was carried out during 1997–1998, and patients were followed for 7 years. Outcome was assessed with CGPSS. Additional psychiatric tests administered included Hamilton Depression Rating Scale, Young Depression Rating Scale, Beck Depression Inventory Scale, Hamilton Anxiety Rating Scale, Young Mania Rating Scale, Brief Psychiatric Rating Scale, Active Symptom Scale, and Negative Symptom Scale. Tests were administered annually for 7 years. Of patients, 68.8% had a marked response (CGPSS score $>3$, improved and usually working, or better), 18.8% had a possible response (CGPSS score 2), and 12.6% did not improve or declined. Evaluating the entire battery of outcome scales revealed significant improvement in depressive, anxiety, and negative symptoms, with no significant change in mania and active symptoms. Three patients experienced minor complications of local infection, transient hallucinations, and extrapyramidal symptoms (10).

## CONCLUSIONS

Two important conclusions can be drawn from the history and modern outcomes of ablative neurosurgical procedures for psychiatric conditions. First, it is imperative to adhere to carefully considered guidelines on the ethical selection of patients for these procedures. A multidisciplinary team of psychiatrists, neurologists, and neurosurgeons should assess candidacy thoroughly before offering surgery. There are no established criteria governing how to determine candidacy for either lesioning or deep brain stimulation (DBS) or how to distinguish between the two. For the former, institutions that offer these procedures have typically established their own criteria, which usually include refractoriness to conventional pharmacologic and behavioral therapy and lack of psychotic or Axis II features. For DBS, at the present time, a substantial fraction of procedures are done within the stipulations of a clinical trial. Inclusion and exclusion criteria tend to be quite similar between lesioning and DBS procedures. In our opinion, the consensus reached in the late 1970s by the Congressional Commission (60) provides an excellent framework by which to determine eligibility for psychiatric surgery.

Second, more recent lesioning studies continue to demonstrate the efficacy and durability of outcomes in these severely disabled patients. It will be important to compare the outcomes of emerging neurosurgical techniques such as DBS with the outcomes accumulated over decades with lesions. The judicious application of lesioning techniques should continue to be considered for appropriately selected patients with severe, refractory psychiatric disorders.

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