Deep Brain, Motor Cortex and Responsive Cortical Stimulation

Table of Contents

Overview .............................................................. 1
Coverage Policy ................................................... 1
General Background ............................................ 2
Coding/Billing Information .................................. 22
References ........................................................ 25

Related Coverage Resources

Botulinum Therapy
Headache and Occipital Neuralgia Treatment
Implantable Infusion Pumps for Non-musculoskeletal Conditions
Transcranial Magnetic Stimulation

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Overview

This Coverage Policy addresses the proposed indications for conventional deep brain stimulation, directional deep brain stimulation, motor cortex and responsive cortical stimulation.

Coverage Policy

Deep Brain Stimulation
Conventional deep brain stimulation (DBS) (excluding directional DBS) is considered medically necessary for the treatment of ANY of the following:

- chronic, medically intractable primary dystonia (including generalized and/or segmental dystonia, hemidystonia, or cervical dystonia/torticollis) for an individual seven years of age or older when used in accordance with the Humanitarian Device Exemption (HDE) specifications of the U.S. Food and Drug Administration (FDA)
- chronic, medically intractable Parkinson disease (PD) when an FDA-approved device is used in accordance with the FDA-approved indications and an individual meets ALL of the following criteria:
• has intractable motor fluctuations or dyskinesia
• is levodopa-responsive
• does not have a significant mental impairment (e.g., dementia, severe depression) or a medical (e.g., stroke, cardiovascular disease) or surgical (e.g., previous ablative surgery such as thalamotomy, pallidotomy) contraindication to conventional DBS
• chronic, medically intractable essential tremor (ET) when an FDA-approved device is used in accordance with the FDA-approved indications

The replacement/revision of a deep brain stimulator generator/battery and/or lead/electrode and/or patient programmer is considered medically necessary for an individual who meets ALL of the above criteria and the existing generator/lead/programmer is no longer under warranty and cannot be repaired.

Conventional DBS for any other indication including, but not limited to, obsessive-compulsive disorder is considered experimental, investigational or unproven.

Directional deep brain stimulations (e.g., Infinity™ DBS system) is considered experimental, investigational and unproven for all indications.

Responsive Cortical Stimulation
Responsive cortical stimulation (e.g., NeuroPace® RNS® System) is considered medically necessary when ALL of the following criteria are met:
• age 18 years or older
• partial onset seizures
• seizures are refractory to two or more antiepileptic medications
• experiencing an average of three or more disabling seizures (e.g., motor partial seizures, complex partial and/or secondarily generalized seizures) per month over the three most recent months
• diagnostic testing confirms localized seizure onset to one or two foci
• not a candidate for focal resection epilepsy surgery
• not a candidate for vagus nerve stimulation

The replacement/revision of a responsive cortical stimulation neurostimulator/battery and/or leads and/or monitor is considered medically necessary for an individual who meets ALL of the above criteria and the existing neurostimulator/lead/monitor is no longer under warranty and cannot be repaired.

Motor Cortex Stimulation
Motor cortex stimulation for any indication is considered experimental, investigational or unproven.

General Background

Conventional Deep Brain Stimulation

Conventional deep brain stimulation (CDBS) involves the delivery of continuous, high-frequency electrical impulses to an area in the brain responsible for movement. The procedure is reversible and causes no permanent damage. Prior to implantation, a stereotactic rigid frame, or frame based system, is secured to the patient's skull, and the initial targeted area is selected using an imaging technique (e.g., magnetic resonance imaging [MRI], computed tomography [CT] or ventriculography). An alternative to the frame-based system is the frameless stereotactic system which may use external fiducial markers and/or internal anatomic landmarks. An electrode is introduced into the brain and test simulations are performed to evaluate and adjust tremor amplitude, diffusion of stimulation and determination of the threshold for paresthesias and speech disturbances. The electrode is connected to a computerized pulse generator which is typically implanted underneath the skin near the collarbone. The CDBS system may be implanted either unilaterally or bilaterally, depending on the distribution of the patient’s symptoms. When the intended targets include both sides of the brain, two separate systems are implanted. The system also includes a handheld therapy controller and a control magnet. Batteries
in the generators typically last from three to five years and are replaced in an outpatient procedure. Some newer devices may have a rechargeable battery (Weintraub, et al., 2007; Holloway, et al., 2005).

CDBS is used for a carefully selected subset of individuals with chronic primary dystonia including generalized and/or segmental dystonia, cervical dystonias (i.e., torticollis), and hemidystonia. In addition, CDBS is considered an established intervention for the treatment of medically refractory essential tremor (ET) and Parkinson disease (PD). CDBS is not a first line therapy and is generally considered when the individual cannot tolerate or has failed pharmacotherapy or when pharmacotherapy is no longer effective.

U.S. Food and Drug Administration (FDA)
The Activa® Dystonia Therapy System (Medtronic Neurological, Minneapolis, MN) was FDA-approved under the Humanitarian Device Exemption (HDE) process. The device was approved for “unilateral or bilateral stimulation of the internal globus pallidus (GPI) or the subthalamic nucleus (STN) to aid in the management of chronic, intractable (i.e., drug-refractory) primary dystonia, including generalized and/or segmental dystonia, hemidystonia, and cervical dystonia (i.e., torticollis) in patients seven years of age or above” (FDA, 2003).

The Activa® Tremor Control System (Medtronic) was approved by the FDA under the premarket approval process (PMA) for “unilateral thalamic stimulation for the suppression of tremor in the upper extremity in patients who are diagnosed with essential tremor or Parkinsonian tremor not adequately controlled by medications and where the tremor constitutes a significant functional disability” (FDA, 1997).

The Activa® Parkinson’s Control Therapy System (Medtronic) was FDA approved in 2002 as a PMA device for “bilateral stimulation of the internal globus pallidus (GPI) or the subthalamic nucleus (STN) for adjunctive therapy in reducing some of the symptoms of advanced, levodopa-responsive Parkinson’s disease that are not adequately controlled with medication”. In November 2015 the FDA modified the approval of Medtronic’s CDBS devices for the treatment of Parkinson disease to read “bilateral stimulation of the internal globus pallidus (GPI) or the subthalamic nucleus (STN) using Medtronic CDBS therapy for Parkinson’s disease is indicated for adjunctive therapy in reducing some of the symptoms in individuals with levodopa-responsive Parkinson’s disease of at least 4 years’ duration that are not adequately controlled with medication”.

There are three different types of Activa neurostimulators. The Activa SC neurostimulator is a single channel device that delivers stimulation to one side of the brain through a lead wire. Two SC neurostimulators may be used to stimulate areas on both sides of the brain. The Activa PC is a dual channel device that can deliver stimulation to one or both sides of the brain using two lead wires and has a nonrechargeable battery. The Activa RC neurostimulator is a rechargeable deep brain stimulation device and has up to 15 years of longevity (Medtronic, 2018).

The Brio Neurostimulation System (St. Jude Medical, Plano, TX) was FDA approved in 2015 as a PMA device for the following indications: 1) bilateral stimulation of the subthalamic nucleus (STN) as an adjunctive therapy to reduce some of the symptoms of advanced levodopa-responsive Parkinson’s disease that are not adequately controlled by medications; 2) unilateral or bilateral stimulation of the ventral intermediate nucleus (VIM) of the thalamus for the suppression of disabling upper extremity tremor in adult essential tremor patients whose tremor is not adequately controlled by medications and where the tremor constitutes a significant functional disability. The approval was based on a randomized controlled trial of patients, age 18–80 years with PD for at least five years duration. The Brio is a rechargeable system.

In February 2009, the Medtronic Reclaim™ CDBS™ Therapy for OCD system was FDA approved as a HDE device and is “indicated for bilateral stimulation of the anterior limb of the internal capsule (AIC) as an adjunct to medications and as an alternative to anterior capsulotomy for treatment of chronic, severe, treatment-resistant obsessive-compulsive disorder (OCD) in adult patients who have failed at least three selective serotonin reuptake inhibitors (SSRIs)”. The power source for bilateral Reclaim™ DBS Therapy for OCD is a one or two dual-program Activa PC neurostimulator or a two single-program Activa SC neurostimulators.

The HDE labeling for the Reclaim system stated that “The safety and probable benefit of CDBS for the treatment of OCD has not been established for the following:
patients with Tourette’s syndrome
patients with primary subclassification of hoarding
patients whose OCD is documented to be less than five years duration
patients whose Yale-Brown Obsessive-Compulsive Scale (YBOCS) score is less than 30
patients who have not completed a minimum of three adequate trials of first and/or second line medications with augmentation
patients who have not attempted to complete an adequate trial of cognitive behavior therapy (CBT)
patients with a previous surgical ablation procedure (e.g., capsulotomy)
patients who are pregnant
patients who are under the age of 18 years
patients with dementia
patients with coagulopathies or who are on anticoagulant therapy
patients without comorbid depression and anxiety
patients with neurological disorders
patients with other serious medical illness including cardiovascular disease, renal or hepatic failure, and diabetes mellitus"

The labeling also stated that “Physicians should carefully consider the potential risks of implanting the brain stimulation system in patients with comorbid psychiatric disorders, including:

- bipolar disorder
- body dysmorphic disorder
- expanded personality impulse-control disorders or paraphilias
- psychotic disorder
- severe personality disorders
- substance abuse
- the inability to control suicidal impulses or a history of suicide attempts

The brain stimulation system may aggravate the symptoms of comorbid psychiatric disorders” (FDA, 2009).

**Dystonia**

Dystonia refers to a diverse group of movement disorders characterized by involuntary muscle contractions that may cause twisting and repetitive movements or abnormal postures. Primary dystonia often begins focally in the legs and progresses to a generalized (i.e., involving all of the body) syndrome. Secondary dystonias are induced by a disease or ingested substance. Dystonias may also be categorized as focal (i.e., one area of the body is involved, such as hemidystonia, cervical dystonia or torticollis), or segmental involving two or more areas.

Treatment options for dystonia include oral medications and chemodenervation (e.g., botulinum toxin [BTX], type A or type B injection therapy). Invasive interventions and surgery for dystonia are generally reserved for those patients who have significant disabilities and are refractory to aggressive medication therapy and BTX. Conventional deep brain stimulation (CDBS) is a reversible, surgical option used for the treatment of primary dystonia including generalized and/or segmental dystonia, hemidystonia, and cervical dystonia or torticollis. CDBS is indicated for individuals age seven years and older who do not respond to pharmacotherapy (i.e., medically intractable).

**Literature Review:** Randomized controlled trials and case series have reported improvement in tremor, speech, walking, performance of activities of daily living, reduction in medication usage, mood and quality of life following CDBS in patients with dystonia (Sarubbo, et al., 2012; Cif, et al., 2010; Mueller, et. al., 2008; Vidailhet, et al., 2007; Hung, et al., 2007; Kiss, et al., 2007; Grips, et al., 2007; Tisch, et al., 2006; Kupsch, et al., 2006; Diamond, et al., 2006; Vidailhet, et al., 2005; Zorzi, et al., 2005; Halbig, et al., 2005; Starr, et al., 2004; Kupsch, et al., 2003).

**Essential Tremor (ET) and Parkinson Disease (PD)**

Essential tremor (ET) is a common movement disorder characterized by postural tremor of the outstretched upper limbs that is absent at rest, not worsened by movement, and not associated with extrapyramidal or
cerebellar signs. For most individuals with ET, symptoms can be managed with propranolol and primidone. Alcohol ingestion temporarily reduces ET symptoms, an effect that may last from 30 minutes to several hours. If medications and alcohol ingestion fail to provide adequate relief, patients with severe, chronic and medically intractable ET become candidates for surgical interventions (e.g., thalamotomy and pallidotomy).

Parkinson disease (PD) is a slowly progressive, chronic neurodegenerative disorder resulting from the death of the cells of the substantia nigra which contain dopamine. Eventually, lack of dopamine leads to hyperactivity in the internal globus pallidus (GPI) resulting in direct over stimulation of the GPI and over stimulation of the subthalamic nucleus (STN) which contributes to the existing over stimulation of the GPI.

Levodopa therapy effectively relieves symptoms in approximately 95% of PD patients. However, over the course of 5–10 years, most levodopa-responsive patients manifest increasingly severe and frequent motor fluctuations and dyskinesia. Motor fluctuations are alterations between periods of being "on," during which the patient experiences a positive response to medication, and being "off," during which the patient experiences a reemergence of the Parkinson symptoms that were suppressed during the "on" state. Motor fluctuations sometimes can be reduced or delayed by changing the schedule and amount of levodopa. Other medicines may be added to levodopa to help with motor fluctuations, such as dopamine agonists, COMT inhibitors, or MAO-B inhibitors. Dyskinesia consists of levodopa-related abnormal, involuntary movements. When levodopa therapy fails, propranolol may be administered as an adjuvant treatment and anticholinergic medications can counteract symptoms in some patients (Liang and Tarsy, 2019).

Patients with PD who are considered candidates for CDBS include those who have been successfully treated with levodopa, but have become unresponsive to the medication (i.e., levodopa-resistant). In general, patients who have a significant mental impairment (e.g., dementia, severe depression, affective disorders, psychosis, and cognitive deficit) are not considered candidates for CDBS. The presence of a significant mental impairment may preclude the ability of the patient to respond to stimulation testing during insertion of the device to assist in proper lead placement and to properly operate the stimulator following insertion. In some cases, it has been reported that CDBS may worsen pre-existing mental conditions (e.g., dementia, cognitive deficits/impairment). Co-morbidities and medical contraindications (e.g., cardiovascular disease, stroke) to implantation are taken into consideration. Surgical contraindications include patients with previous ablative surgery (e.g., thalamotomy, pallidotomy) or conditions that may increase the risk of intracranial hemorrhage (Benabid, 2009; Olanow, et al., 2009; Pahwa, et al., 2006).


**Professional Societies/Organizations:** Based on a systematic review of the literature, the Congress of Neurological Surgeons (Rughani, et al., 2018) made the following level 1 recommendations (generally accepted principles for patient management that reflect a high degree of clinical certainty) on deep brain stimulation for the treatment of Parkinson’s disease:

- “Given that bilateral STN DBS [subthalamic nucleus deep brain stimulation] is at least as effective as bilateral GPI DBS [globus pallidus internus deep brain stimulation] in treating motor symptoms of Parkinson’s disease (as measured by improvements in UPDRS-III scores [Unified Parkinson’s Disease Rating Scale, Part III]) consideration can be given to the selection of either target in patients undergoing surgery to treat motor symptoms.
- When the main goal of surgery is reduction of dopaminergic medications in a patient with Parkinson’s disease, then bilateral STN DBS should be performed instead of GPI DBS.
- There is insufficient evidence to make a generalizable recommendation regarding the target selection for reduction of dyskinesias. However, when the reduction of medication is not anticipated and there is a goal to reduce the severity of “on” medication dyskinesias, the GPI should be targeted.
• When considering improvements in quality of life in a patient undergoing DBS for Parkinson’s disease, there is no basis to recommend bilateral DBS in one target over the other.

• If there is significant concern about cognitive decline, particularly in regards to processing speed and working memory in a patient undergoing DBS, then the clinician should consider using GPi DBS rather than STN DBS, while taking into consideration other goals of surgery.

• If there is significant concern about the risk of depression in a patient undergoing DBS, then the clinician should consider using pallidal rather than STN stimulation, while taking into consideration other goals of surgery.

• There is insufficient evidence to recommend bilateral DBS in one target over the other in order to minimize the risk of surgical adverse events.”

In practice parameters for the treatment of PD nonmotor symptoms, the American Academy of Neurology (Zesiewicz, et al., 2010) stated that there was insufficient evidence to support CDBS for the treatment of urinary incontinence in PD.

The Quality Standards Subcommittee of the American Academy of Neurology (Zesiewicz, et al., 2011; reaffirmed 2014) practice parameter on therapies for ET stated that CDBS of the Vim thalamic nucleus is effective in reducing contralateral limb tremor in medically refractory ET. Bilateral CDBS is necessary to suppress tremor in both upper extremities, but there are insufficient data regarding the risk-benefit ratio of bilateral versus unilateral CDBS in the treatment of ET. Both CDBS and thalamotomy are effective in suppressing tremor in ET; however, CDBS is associated with fewer adverse events. The decision to use either procedure should be based on each individual’s circumstances and risk for intraoperative complications.

Epilepsy
Epilepsy is a common condition with repeated seizures caused by abnormal bursts of electrical activity in certain areas in the brain. Seizures may cause problems with muscle control, movement, speech, vision and/or awareness. Conventional DBS (CDBS) of the thalamus, STN, cerebellum, hippocampus, caudate nucleus, mammillary nuclei and anterior nucleus of the thalamus (ANT) has been proposed for the treatment of drug-refractory epilepsy. The ANT, the centromedian nucleus of the thalamus, and the hippocampus are most frequently employed. It has also been proposed that individuals who do not respond to vagal nerve stimulation or surgical resection may be CDBS candidates. Although improvements in seizures of 70%–80% have been reported, the results have rarely been reproducible. Studies have primarily been in the form of small patient populations with short-term follow-ups with heterogeneity of the target area. There is ongoing research regarding identification of the best target for stimulation for the treatment of epilepsy. Therefore, CDBS for epilepsy is still considered in the experimental stage (Bouwens, et al., 2018; Middlebrooks, et al., 2018; Cukiert and Lehtimake; 2017; Cukiert, et al., 2017; Halpern, et al., 2008; Villanueva, et al., 2007).

U.S Food and Drug Administration (FDA): FDA approved the Medtronic DBS system for the treatment of epilepsy on Apr 27, 2018. The System is indicated for bilateral stimulation of the anterior nucleus of the thalamus (ANT) as an adjunctive therapy for reducing the frequency of seizures in individuals 18 years of age or older diagnosed with epilepsy characterized by partial-onset seizures, with or without secondary generalization, that are refractory to three or more antiepileptic medications. “The Medtronic DBS System for Epilepsy has demonstrated safety and effectiveness for patients who average six or more seizures per month over the three most recent months prior to implant of the DBS system (with no more than 30 days between seizures)”. The main components of the device include the implantable Active PC neurostimulator (INS), leads, extension, external neurostimulator (ENS), clinician programmer, and patient programmer (FDA, 2018).

Literature Review: Herman et al. (2019) conducted a prospective, randomized, double-blinded study to evaluate seizure frequency and safety of anterior thalamic nucleus (ATN) deep brain stimulation (DBS) for the treatment of epilepsy. Eighteen patients were blinded to receive active stimulation or no stimulation for six months. All patients received active stimulation after the first six months. Eligible patients were adults aged 18–70 years, minimum IQ of 70, diagnosed with focal epilepsy, with or without secondary generalization. Exclusion criteria were psychogenic non-epileptic seizures, generalized epilepsy, pregnancy, other neurological diseases and serious medical conditions including psychiatric illnesses. All patients were not candidates for resective epilepsy surgery. Patients were followed up at 3, 6, 9 and 12 months for changes in seizure frequency, changes in types of seizures and possible adverse effects. There was no significant difference in seizure frequency
between the two groups at the end of the blinded period at six months. Three patients experienced an increase in seizure frequency (>20%) which curtailed adding an additional 20 patients to the study, as was planned. Adverse events included: an increase in seizure activity (n=3), headache, dizziness, vertigo, memory deficit, transient depression, “strange thoughts”, changed perception of reality, problems finding words and altered circadian seizure pattern. Reported positive effects included: more energy, better sleep, shorter and less intense seizures, shorter postictal phase, less frequent seizures with corresponding falls and traumas, and better cognitive functioning. Author noted study limitations included a possible micro-lesion effect. Additional limitations included the small patient population and short-term follow-up. The main finding was that there was no significant difference in seizure frequency after the blinded period between patients with or without stimulation. Larger, well-designed studies with large patient populations are needed to determine the safety and efficacy of DBS for the treatment of epilepsy.

Chang and Xu (2018) conducted a systematic review and meta-analysis of studies investigating DBS in patients with refractory temporal lobe epilepsy (TLE). The primary outcome was remarkable seizure reduction (RSR) in the last reported follow-up. RSR was defined as a seizure frequency reduction of at least 70%. Study inclusion criteria were: (1) postoperative seizure outcomes following DBS collected from at least four patients with refractory TLE, (2) a mean or median follow-up of ≥ 1 year, and (3) outcomes measured with a seizure frequency reduction scale or comparable tool. Eight case-control studies (n=61) met inclusion criteria. The postoperative RSR rate pooled from the eight included studies was 59%. Hippocampal and anterior thalamic nuclei (ATN) sites of stimulation had similar odds of producing RSR. Only one of the eight studies examined seizure outcomes after DBS was delivered to the thalamic nuclei. Due to the small patient populations (n=4–11) definitive conclusions re DBS for the treatment of refractory TLE could not be established.

Li and Cook (2018) conducted a systematic review of the literature to evaluate DBS for the treatment of drug-resistant epilepsy. One randomized controlled trial and sixteen noncontrolled studies investigated DBS of the anterior nucleus of the thalamus (DBS-ANT). With the exception of two studies (n=87 and 110), patient populations ranged from 2–16. Four randomized controlled trials and nine noncontrolled studies evaluated DBS of hippocampus (HC) with patient populations ranging from 2–95. Two randomized controlled trials and six noncontrolled trials evaluated stimulation of the centromedian nucleus of the thalamus (CMT) (n=2–11) and two randomized controlled trials and six noncontrolled studies evaluated cerebellum DBS. One study reported on stimulation of the nucleus accumbens (NA). Mean follow-up from the studies primarily ranged from ten days to four years and the type of epilepsy varied. Outcome measures were varied and results were conflicting with some studies reporting no improvement in outcomes and others reporting significant improvement (e.g. reduction in seizure frequency). Pooled data indicated that stimulation of the anterior nucleus of the thalamus (ANT) and hippocampus (HC) resulted in a decrease in the frequency of refractory seizures. Half of all patients from clinical studies experienced a 46%-90% seizure reduction with ANT-DBS and a 48%-95% seizure reduction with HC-DBS. The efficacy of stimulation of CMT, CB, STN, and other targets were inconclusive due to the lack of evidence. Adverse events were either surgical (e.g., hemorrhage, wound infection, implant site pain), stimulation-related (e.g., worsening/new seizures, paresthesia, dizziness, memory/cognitive changes) and equipment related events including lead migration, lead displacement, lead fracture, erosions and equipment infections. The authors noted that response to DBS for the treatment of epilepsy varied based on the presence of structural abnormalities found on imaging for ANT and HC stimulation, electrode placement and the types of seizure/syndromes being treated. Limitations of the studies included: small patient populations; short-term follow-ups; risk of bias; patient-recorded seizure events; and heterogeneity of the types of seizures, target areas stimulated, patient characteristics, data collection methods and outcome reporting and criteria. Large-scale clinical trials are needed to identify the most effective stimulation parameters and the predictors of patient response as well as, the indications for DBS for the treatment of epilepsy. Patient selection criteria, the most effective target areas, stimulation parameters and long-term outcomes have not been established.

Zhou et al. (2018) conducted a systematic review of the literature to investigate the safety and efficacy of DBS for the treatment of epilepsy. Forty-one articles met the inclusion criteria of reporting clinical outcomes involving at least one patient. The most frequently studied stimulation targets were the ANT (n=20 studies; 220 patients), CMT (n=7 studies; 35 patients), HCP (n=10 studies; 73 patients), and other alternative targets (n=7 studies). Some studies evaluated multiple targets and were included more than once. Overall, the number of patients per study ranged from 1–16 and follow-ups ranged from 48 hours to five years. ANT, CMT and HCP with responder rates of 44%-100%, 50%-100%, and 60%-100%, respectively were reported. Other alternative targets have
demonstrated varying degrees of success. Studies have included small patient populations and short-term follow-ups. Long-term follow-ups are lacking. Additional evidence supporting DBS for the treatment of refractory epilepsy is needed. Patient selection criteria and targeted areas for stimulation have not been established.

Sprengers et al. (2017) conducted a Cochrane systematic review of randomized controlled trials to assess the safety, efficacy and tolerability of deep brain (DBS) and cortical (neocortex and cerebellar cortex) (CDBS) stimulation for the treatment of refractory epilepsy. Twelve randomized controlled trials met inclusion criteria. Comparators included sham therapy, respective surgery or antiepileptic drug therapy. Outcomes included seizure freedom, responder rate, percentage seizure frequency reduction, adverse events, neuropsychological outcomes and quality of life. Follow-ups ranged from one to three months. The studies included: anterior thalamic CDBS (one study; n=109), centromedian thalamic CDBS (two trials; n=20), cerebellar stimulation (three trials; n=22), hippocampal CDBS (four trials; n=21), nucleus accumbens (one trial; n=4) and responsive ictal onset zone stimulation (one trial; n=191). According to the authors, moderate-quality of evidence did not statistically or clinically demonstrate significant changes in the number of subjects who were seizure-free or had a ≥ 50% reduction in seizure frequency one to three months following anterior thalamic DBS in (multi) focal epilepsy, responsive ictal onset zone stimulation in (multi) focal epilepsy patients and hippocampal DBS in (medial) temporal lobe epilepsy. A statistically significant reduction in seizure frequency was found for anterior thalamic DBS compared to sham stimulation, responsive ictal onset zone stimulation, and hippocampal DBS. Both anterior thalamic DBS and responsive ictal onset zone stimulation did not demonstrate a clinically meaningful impact on quality of life following three months of DBS. No statistically significant effects were reported following centromedian thalamic DBS, nucleus accumbens DBS and cerebellar stimulation. The limited number of patients preclude firm statements on safety and tolerability of hippocampal DBS. Adverse events included postoperative asymptomatic intracranial hemorrhage and postoperative soft tissue infections. Large and well-designed RCTs are needed to validate and optimize the efficacy and safety of invasive intracranial neurostimulation treatments.

Troster et al. (2017) reported on the incidence of memory and depression adverse events (AE) in the Stimulation of the Anterior Nucleus of the Thalamus for Epilepsy (SANTE) randomized control trial blinded phase (first three months). Additionally, they reported on the relationship of memory and depression to objective neurobehavioral measures, baseline characteristics, quality of life and long-term neurobehavioral outcome (through year seven). The SANTE trial investigated deep brain stimulation (DBS) of the anterior nucleus of the thalamus (ANT) for treatment of localization related epilepsy. Patients (n=110) were included if they were adults with at least six partial or secondarily generalized seizures per month who had failed at least three antiepileptic drugs. Excluded were patients with IQ <70, inability to complete neuropsychological testing, nonepileptic seizures, and any of the following in the five years preceding baseline evaluation: history of substance abuse, psychiatric illness hospitalization, suicide attempt, or symptoms of psychosis (hallucinations, delusions) not related to medication or an ictal or post-ictal state. Neuropsychological measures were tested using the following: verbal memory: California Verbal Learning Test, Second Edition (CVLT-II) Trials 1–5 total and long delay free recall; visual memory: Brief Visuospatial Memory Test- Revised (BVMT-R) total recall and delayed recall; and depression: Profile of Mood States (POMS) Depression scale. Neuropsychological assessments were conducted at three months and one month prior to implantation and at week four, month four, month seven, and annually through year seven following implantation. At three months, the control patients crossed over to DBS. During the blinded phase adverse events were reported as follows: depression (active n=8, 14.8%; control n=1, 1.8%) (p=0.016) and memory AE (active n=7, 13%; control n=1, 1.8%) (p=0.032). In half of the active group (n=4/8) depression and all memory events resolved. Other adverse events reported included: “confusional state” (7.4% active, 0% control) and “anxiety” (9.3% active, 1.8% control). Seven year evaluation reported no significant cognitive declines, neurobehavioral problems (e.g., apathy, disinhibition), subjective cognitive declines, or affective distress (depressive and anxious symptoms). Author noted limitations included the lack of statistical power and lack of a long-term control group. Additional well-designed studies with large patient populations are needed to determine the safety and efficacy of this treatment.

Salanova et al. (2015) reported on the efficacy and safety results of the Stimulation of the Anterior Nucleus of the Thalamus for Epilepsy (SANTE) randomized control trial. The SANTE trial investigated deep brain stimulation of the anterior nucleus of the thalamus (ANT) for the treatment of localization related epilepsy (Fisher et al., 2010). The objective of the research was whether seizure frequency continued to improve over time with open-label anterior thalamic stimulation. Starting 13 months after device implantation, stimulation parameters were adjusted
Fisher et al. (2010) conducted a multicenter, double-blind, randomized controlled trial (n=110) to evaluate CDBS for the treatment of epilepsy. Patients underwent bilateral stimulation of the anterior nuclei of the thalamus for epilepsy (SANTE). Diagnosis included medically refractory partial seizures including secondarily generalized seizures. Postoperatively, patients kept a daily diary of seizure activity for primary analysis. One month following implantation, patients were randomized to stimulation (n=54) or no stimulation (n=55) (one outlier patient was excluded due to lack of diary information). The intent-to-treat (ITT) analysis, with exclusion of the one patient, across the three-month blinded phase favored the stimulation group (p=0.039) and showed a significant decrease in seizure activity (p=0.039). Complex partial seizures significantly improved more in the stimulation group compared to the no stimulation group (p=0.041, outlier removed). The severity of seizures decreased more in the stimulated group (p=0.047) and injuries from seizures was greater in the control group (p=0.01). Effectiveness of therapy was dependent on the region of the seizure origin. Patients with seizure origin in frontal, parietal or occipital regions did not demonstrate significant differences in seizure reduction between the two groups. Following completion of the blinded period, 108 patients received stimulation for an additional 1–10 months. ITT analysis of patients who elected to continue stimulation following the blinded period revealed a 50% responder rate in 81 patients (54%) at 25 months, and 42 patients (67%) at 37 months. Three patients had > 50% worsening of seizures. At the two-year follow-up, 13 of 81 patients (16%) had a ≥ 90% median seizure frequency reduction compared to baseline. Fourteen patients (13%) were seizure-free for at least six months, eight patients (7.3%) for at least one year, four patients (3.6%) for at least two years, and one patient (0.9%) was seizure-free for more than four years. Adverse events included paresthesia, infection, implant site pain, depression, asymptomatic hemorrhages and new seizure events. Eighteen patients withdrew due to adverse events. Limitations of the study include lack of a long-term control group and no detailed analysis of medication changes during the follow-up phase. Additional well-designed comparative studies with large patient populations are needed to confirm the safety and efficacy of this treatment.

Other Conditions
CDBS has been proposed for the treatment of multiple other disorders including: addictions (e.g., smoking, alcohol); aggressive behavior; Alzheimer disease; anorexia nervosa; camptocormia; cancer; cerebral palsy; cluster headache; chronic pain; central pain from spinal cord injury; depression; Huntington’s disease; Lesch-Nyhan syndrome; movement disorders secondary to structural lesions (e.g., basal ganglionic stroke, tumor or
vascular malformation); multiple sclerosis tremor; non-idiopathic Parkinson disease ("Parkinson Plus"); obesity; obsessive-compulsive disorder; restless leg syndrome; short-lasting, unilateral, neuralgiform headache (SUNCT); tardive dyskinesia; tremors of the head and voice; trigeminal neuralgia; trigeminal neuropathy; Tourette syndrome (i.e., Tics); secondary tremors from birth injury, trauma, toxins and stroke; and disorders of consciousness (e.g., minimally conscious, vegetative state) (Taghva, et al., 2012; Lyons, 2011; Nyhan, et al., 2014; Prévinier, et al., 2009; Larson, 2008; Damier, et al., 2007; Kern and Kumar 2007; Mink, et al., 2006; Skidmore, et al., 2006; Anderson and Arciniegos, 2004).

There is insufficient evidence in the published peer-reviewed scientific literature to support CDBS for the treatment of any of these conditions. Studies are primarily in the form of case reports and case series with small patient populations (n=2–10) and short-term follow-ups. In some studies, various areas of the brain are used for stimulation and there is a lack of consensus as to which area/areas should be targeted for each condition. Definitive patient selection criteria have not been established. Comparison of CDBS to established pharmacotherapy and surgical interventions is lacking. CDBS devices are not FDA approved for treatment of these conditions.

Cerebral Palsy: Cerebral palsy (CP) is one of the most common causes of secondary dystonia. Approximately 10%–15% of patients develop a dyskinetic movement disorder which starts in early infancy and progresses throughout adulthood. Patients may become severely disabled in their motor function. CDBS is a proposed treatment option for those individuals in whom pharmacotherapy is ineffective and/or the side effects limit dosing. There is insufficient evidence to support CDBS for CP dyskinesia.

Koy et al. (2013) conducted a systematic review and meta-analysis to evaluate CDBS for the treatment of dyskinetic cerebral palsy. Twenty articles consisting of 11 case reports and 19 case series (n=3-14) met inclusion criteria. The analysis included 68 patients who had undergone CDBS and outcomes were assessed by the Burke-Fahn-Marsden Dystonia Rating Scale movement (BFMDRS-M) and disability scores (BFMDRS-D). At the 12-month median follow-up, a significant improvement was seen in the postoperative BFMDRS-M (p<0.001) and the BFMDRS-D (p<0.001). The authors noted that the published results were "very variable" and overall, response for secondary dystonia was "far less dramatic" than reported results for primary dystonia. Limitations of the meta-analysis include the low level of evidence, small number of patients, heterogeneity of the procedures and selection of primary CDBS target, variable short-term follow-up times with some studies only reporting one post-operative BFMDRS score, and quality-of-life data was only reported in four studies.

Chronic Pain: CDBS has been proposed for the treatment of various types of chronic, intractable pain. However, because of surgical and nonsurgical treatment interventions, its use has substantially decreased (Kern and Kumar, 2007). Two studies were initiated in the 1980s seeking FDA approval but were prematurely concluded; thus, CDBS for the treatment of chronic pain has not received FDA approval (Owen, et al., 2007). Studies are primarily in the form of case series with small patient populations (n=34–56) and short term follow-ups (Owen et al., 2007; Rasche, et al., 2006).

In a meta-analysis, Bittar et al. (2005) found six studies, case series and retrospective reviews, which met inclusion criteria. Follow-up ranged from one month to 15 years. A variety of stimulation sites and methods were utilized. Patients selected for CDBS included individuals with pain of known organic origin who failed or poorly tolerated conventional therapies and did not have neuroses/psychoses or severe depression. Twenty-four different pain etiologies (n=1–103) were included (e.g., phantom limb and stump pain, spinal cord pain and/or injury, peripheral neuropathy/radiculopathy, cancer pain and anesthesia dolorosa). The authors reported that CDBS was more effective for nociceptive pain than for deafferentation pain (p<0.01). Success rates of up to 80% were reported in patients with low back pain (n=103) and failed back surgery syndrome (n=59).

Cluster Headache: A cluster headache is a severe, chronic headache that typically occurs in cyclical patterns (i.e., clusters) on one side of the face at the same time of the day for several weeks. Due to the severity of pain, cluster headaches are often referred to as “suicide headaches.” Treatment options include pharmacotherapy and oxygen administration. CDBS has been proposed for the treatment of severe cluster headaches that are refractory to medical management, but there is insufficient evidence in the published peer-reviewed literature to support its effectiveness in this patient population.
Fontaine et al. (2010) conducted a randomized, crossover, double-blind, multicenter study including 11 patients with refractory chronic cluster headaches. Patients were randomized to two, one-month periods of active stimulation vs. sham stimulation separated by a one-week wash-out period. Thereafter, a 10-month open phase was conducted. At the end of the crossover period, there was no significant difference in the frequency of weekly attacks in either group. Following the 10-month open phase, the frequency of the attacks significantly decreased (p=0.08) and patients reported reduced emotional impact. Three “serious” adverse events included an infection requiring removal of the device, loss of conscious with hemiparesia, and severe micturition syncope episodes with hypotension. The study is limited by the small patient population and the short-term follow-up. As the authors noted, due to the conflicting results in the blinded phase and the open phase additional randomized controlled trials are needed to determine the clinical utility of CDBS for cluster headaches.

**Depression:** Depression is an illness characterized by persistent sadness, anxiety, hopelessness, helplessness, pessimism, and a loss of energy and interest in activities. It typically interferes with the activities of daily living and normal functioning (Hauptman, et al., 2008). CDBS has been proposed for the treatment of chronic depression nonresponsive to conventional therapies (e.g., behavioral therapies, pharmacotherapy). There is insufficient evidence in the peer-reviewed literature to support CDBS for depression. Studies are primarily in the form of small case series (n=15–20) with short-term follow-ups (Narang, et al., 2016; Lozano et al., 2012; Kennedy, et al., 2011; Malone, et al., 2009; Lozano et al., 2008).

Kisely et al. (2018) conducted a systematic review and meta-analysis to investigate the clinical efficacy and safety of deep brain stimulation (DBS) for the treatment of depression. A total of seven double-blinded randomized control trials and two single-blinded cross over trials met inclusion criteria. Patient population ranged from 4–90 (n=200 patients). Included studies were single- or double placebo controlled, crossover, and parallel-group trials in which DBS was compared with sham treatment using validated scales: Beck Depression Inventory (BDI), Hamilton Depression Rating Scale (HAM-D), and Montgomery–Asberg Depression Rating Scale (MADRS). Studies were excluded if they did not have a sham comparator. The intervention was deep brain stimulation to the sub-callosal cingulate (SCC) gyrus (n=5 studies), the medial forebrain bundle (n=2 studies), the related structures of the anterior limb of the internal capsule (n=1 study) and ventral capsule/striatum (n=1 study). The comparator was sham treatment. The primary outcome measured was a reduction in depressive symptoms using a validated scale. Secondary outcomes included comorbid psychiatric symptoms, global functioning, cognition, and adverse effects. Length of follow-up ranged from one day to 26 weeks. Outcome results were conflicting. Four studies reported no significant difference between active and sham control groups. For those studies that reported an improvement in depression rating scales on active treatment, a positive response time varied from 1–8 weeks. There was no significant difference in the secondary outcomes measures of quality of life, global functioning, or neuropsychiatric outcomes. The most frequent adverse events were increased depression (n=33), device related discomfort (n=38), pain/erosion around the incision (n=23), agitation (n=15), headache (n=24) and infection (n=14). Other serious adverse events included hemorrhage, delirium, nausea/vomiting, hearing/visual disturbances, seizures, suicide attempts, suicidal ideation, seizures, fatigue and hospital admission. Limitations of this review included the small patient populations, short term follow ups, limited number of studies, and low quality of the studies. Patient selection criteria, length of optimization period and target location for deep brain stimulation have not been established. Additional well-designed multi-center randomized controlled trials are needed to establish the safety and efficacy of this treatment for depression.

Zhou et al. (2018) conducted a systematic review and meta-analysis to investigate the safety and efficacy of deep brain stimulation (DBS) for the treatment of depressive symptoms in treatment-resistant depression (TRD). A total of 14 studies met the inclusion criteria. The number of patients per study ranged from 3–25. Included studies investigated DBS for improvement of depressive symptoms that were evaluated using either the Hamilton depression rating scale (HDRS) or Montgomery–Asberg depression rating scale (MARDs) in TRD patients. Studies that added or changed anti-depressants during the DBS trial were excluded. Abstracts, case studies, reviews, and duplicate cohorts were also excluded. Deep brain stimulation was used targeting one of these four regions of the brain: subcallosal cingulate gyrus (SCG), ventral capsule/ventral striatum (VC/VS), medial forebrain bundle (MFB), and nucleus accumbens (NAcc). The primary outcome was a decrease in depressive symptoms as evaluated by HDRS and MADRS scores from baseline to post treatment. Length of follow up was up to 12 months, but varied between studies. The overall response rate showed a significant reduction in HDRS after DBS stimulation in the four regions: SCG (p<0.00001), VC/VS (p=0.005), MFB (p=0.0001), and NAAa (p=0.003). The pooled results of the MADRS also showed a reduction in the following
areas: SCG (p=0.001), VC/VS (p=0.0002), and MFB (p<0.0007). Adverse events included pain (incisional site [n=7] and headache [n=9]), infection (n=8), swollen eye (n=12), nausea, dizziness, worsening depression (n=12), suicide attempts (n=10), agitation (n=12) and sleep disturbances (n=10). Limitations of this review include heterogeneity of clinical trial designs, varying treatment durations and stimulation parameters, lack of comparators and small sample sizes. The optimal target brain regions and treatment stimulation for DBS for the treatment of depression have not been determined. Well designed, multi-institutional studies with large patient populations are needed to determine the safety and efficacy of this DBS for this subpopulation.

Bergfeld et al. (2016) conducted a randomized, cross-over study (n=25) to investigate CDBS for treatment-resistant depression (TRD). Patients first entered a 52-week open-label trial during which they received bilateral implants of four contact electrodes followed by optimization of CDBS. The optimization phase ended when a stable response of at least four weeks was reached or after a maximum of 52 weeks. Medication adjustments were made as clinically indicated. Immediately following the open-label phase of the study, patients entered the randomized, double-blind crossover phase consisting of two blocks of six weeks during which the CDBS stimulator was on (active) or off (sham). The 17-item Hamilton Depression Rating Scale (HAM-D-17) was the main outcome measure used in the optimization phase. The primary outcome of the crossover phase was the difference in the HAM-D-17 scores (range 0–52; higher score more severe symptoms) between active and sham CDBS. Responders were defined as experiencing a ≥50% decrease of the HAM-D-17 score compared with baseline and partial responders were defined as achieving ≥25 but <50% decrease of the HAM-D-17 score. Remission was defined as a HAM-D-17 score of ≤7 at optimization of settings. In the optimization phase significant improvements were accomplished in the mean HAM-D-17 scores which decreased from 22.2 at baseline to 15.9 (p=0.001), Montgomery-Åsberg Depression Rating Scale scores decreased from 34.0 to 23.8 (p<0.001), and Inventory of Depressive Symptomatology–self-report scores changed from 49.3 to 38.8 (p=0.005). Following the optimization phase, ten patients (40%) were classified as responders and 15 (60%) as nonresponders. Nine responders and seven nonresponders entered the randomized crossover phase. During active CDBS, patients scored significantly lower on the HAM-D-17 scale (13.6 than during sham CDBS (23.1) (p<0.001). Serious adverse events included severe nausea during surgery (n=1), suicide attempt (n=4) and suicidal ideation (n=2). Limitations of the study include the small patient population, short-term follow-up and loss of nine patients to randomization. Also, the optimization phase exceeded the maximum of 52 weeks in six patients, which could have led to a higher response rate. Larger randomized controlled trials and further specification of targets and the most accurate setting optimization are needed to support CDBS for the treatment of TRD.

Berlim et al. (2014) conducted a systematic review and meta-analysis to evaluate CDBS of the subgenual cingulate cortex (SCC) for treatment-resistant depression. Four observational studies (n=66) met inclusion criteria. Remission rates were 16.7% at three months (n=66), 24.1% at six months (n=66) and 26.3% at 12 months (n=63). Response rates were 36.6% at three months, (n=66), 53.9% at six months (n=66) and 39.9% at 12 months. There was a significant reduction in depression rates between months three and six (p=0.001), but not thereafter. Loss to follow-up at 12 months was 10.8%. In addition, the studies were open label with short-term follow-up and small patient populations. There is insufficient evidence to support CDBS of SCC for treatment-resistant depression.

Morishita et al. (2014) conducted a systematic review to evaluate the safety and efficacy of CDBS for treatment-resistant major depressive disorder (MDD). A total of 22 clinical trials met inclusion criteria. Five unique CDBS approaches using different targets were identified. The targets included nucleus accumbens, ventral striatum/ventral capsule, subgenual cingulate cortex, lateral habenula, inferior thalamic nucleus, and medial forebrain bundle. Only one published controlled trial was found. All studies treated patients with severe, medication refractory MDD, or rarely bipolar disorder and three studies were controlled with sham stimulation. Overall the response rates (percentage of patients with>50% improvement on the Hamilton Depression Rating Scale) ranged from 40%–60%. Most complications were minor surgery-related issues (e.g., superficial infection). Completed suicide and suicide attempts were the most significant adverse events following CDBS surgery and happened following CDBS with and without stimulation. Several studies excluded patients with suicidal ideation. Limitations of the studies included: small patient populations; heterogeneity of inclusion criteria and outcome measures; duplication of patients across studies. The authors noted that no class I evidence exists in the literature supporting CDBS for MDD. The optimal CDBS targets are unclear. Therefore, CDBS for MDD is considered experimental.
In a Directory Report (2012; reviewed 2013-2016) Hayes reported that there is insufficient evidence to support CDBS for treatment-resistant depression. Patient selection criteria, the optimum treatment characteristics and predictors of response have not been established. The overall quality of the evidence is low with lack of randomization and small patient populations.

The Canadian Network for Mood and Anxiety Treatments (CANMAT) (Milev, et al., 2016) conducted a systematic review to update the 2009 guidelines for the treatment of adults with unipolar major depressive disorders and concluded that CDBS was still considered investigational. According to the authors, evidence investigating CDBS for the treatment-resistant depression (TRD) is based on nonrandomized, open-label studies with small patient populations (n<20). Response rates were reported between 30%–60% and remission rates 20%–40% at 3–6 month follow-ups. Two multicenter randomized controlled trials comparing CDBS to sham were discontinued due to lack of efficacy. The optimal stimulation parameters for various brain targets and outcomes reporting long-term effects and treatment for relapse are unknown.

**Multiple Conditions:** Appleby et al. (2007) conducted a meta-analysis of 546 relevant articles (i.e., 303 clinical trials, 72 case series, 130 case reports) to “characterize the risks and benefits of CDBS and to assess its possible use within the psychiatric setting.” Three percent of the studies included patients with headaches, chronic pain, epilepsy, OCD and depression. Improvements in mentation, mood and behavior were reported in ten studies, six studies reported worsening and two reported no change. An improvement in chronic pain was reported in 26 studies, with no improvement in three studies and worsening of pain in two studies. Improvements in OCD scores were reported in eight studies with one study reporting no differences. Six studies indicated an improvement in anxiety, seven studies included improved cognition, three reported worsening of cognition, and in 13 studies cognition was unchanged. Three studies used depression as the primary indicator of treatment outcomes and 34 used depression as a secondary measure. Of the studies evaluating depressive symptoms, an improvement was reported in 83.3% of the studies, 2.7% reported worsening and 14% reported no change. The authors stated that because of the number of studies that did not report on post-CDBS mood, the findings of improvement in depressive symptoms should be treated with caution. Following implantation, suicide/attempted suicide and episodes of depression, hypomania and anxiety were reported. Limitations of the studies included: the heterogeneity of the studies, categorical variables (i.e., improvement, no improvement) in outcome measures, lack of outcomes separated by lead placement site, inclusion of case reports and the lack of studies that reported side effects.

**Multiple Psychiatric Disorders:**
Naesström et al. (2016) conducted a systematic review to identify studies on CDBS for psychiatric indications. Fifty-two studies including case reports (n=10) and case series met inclusion criteria. Eighteen studies (n=112) investigated CDBS for chronic, therapy-resistant OCD in six different anatomical targets and nine studies (n=100) used CDBS in five different targeted areas for the treatment of chronic, therapy-resistant MDD. Additional studies included CDBS for the treatment of Tourette’s syndrome (n=57), primary anxiety disorder, alcohol addiction, anorexia nervosa, heroin addiction and autism with aggression and self-mutilation. The most common reported complications were infection and hardware malfunction. Limitations of the studies included: small patient populations (n=3–26), heterogeneity of treatment targets, short-term follow-ups (e.g., < 24 months), lack of a comparator, heterogeneity in evaluation tools and definitions of response and remission. The safety and efficacy of the different stimulation targets and which targets are effective for which conditions have not been established.

Nangunoori et al. (2013) conducted a systematic review and meta-analysis in order to better characterize the evidence supporting CDBS for major depressive disorder (MDD), obsessive-compulsive disorder (OCD) and Tourette’s syndrome (TS). Studies were included that used a primary, single, standardized outcome scale. A total of 24 studies met inclusion criteria. Four studies were related to MDD (n=48), ten to OCD (n=64) and ten to TS (n=46). Meta-analysis showed that all studies had a clinically detectable and statistically significant reduction in disease-specific outcome scale scores when CDBS was used. The average improvement was 2.47 standard deviations for MDD, 2.77 for OCD and 2.97 for TS. Limitations of the studies included the lack of randomized controlled trials, the limited number of studies with small patient populations, short-term follow-ups, and heterogeneity of secondary outcome measures, stimulation parameters and OCD studies.
Lakhan and Callaway conducted a systematic review of clinical trials (n=17), including case series (some with randomization of on/off sessions) and case reports to evaluate outcomes of CDBS for the treatment of obsessive-compulsive disorder (OCD) and treatment resistant depression (TRD). Nine OCD studies (n=42 total patients; range, 1–18 per study), seven TRD studies (n=67 total patients; range 1–21 per study), and one study with one patient with both disorders met inclusion criteria. Follow-up ranged from 3–39 months. Due to the sparse data, meta-analysis could not be conducted. The authors noted that the reports of suicide and psychoses following CDBS were “disturbing,” and criteria for patient selection and electrode placement need to be established.

Multiple Sclerosis (MS): Multiple sclerosis (MS) is a disease of the central nervous system (CNS) that is characterized by areas of demyelination in the white matter of the brain and by recurrent exacerbations of neurologic dysfunction. It is estimated that approximately 10% of MS patients have disabling tremors. Although CDBS has been proposed as a treatment option for MS, there is insufficient evidence to support the safety and efficacy of CDBS for this condition.

Obsessive-Compulsive Disorder (OCD): OCD is a type of anxiety disorder in which individuals have unwanted thoughts (obsessions) and repeated behaviors (compulsions) over and over again. Severe cases of OCD can be disabling and interfere with activities of daily living and relationships. Treatment for OCD may include pharmacotherapy (e.g., selective serotonin reuptake inhibitors [SSRIs] and/or antipsychotic medications) and/or psychotherapy. CDBS has been proposed as a treatment option for chronic, severe OCD in individuals who are unresponsive to adequate medical and behavioral therapy including, but not limited to failure of at least three SSRIs (Kuhn, et al., 2010; FDA, 2009; Mallet, et al., 2008).

There is insufficient evidence in the published peer-reviewed literature to support CDBS for the treatment of OCD. Studies are primarily in the form of small case series (n=2–16) (De Vloo et al., 2018; Ooms, et al., 2013; Denys, et al., 2010; Okun, et al., 2007; Greenberg, et al., 2006; Rauch, et al., 2006) and case reports.

A 2018 Hayes search and summary concluded that there is insufficient published evidence to assess the safety and/or impact on health outcomes for deep brain stimulation (DBS) for the treatment of obsessive compulsive disorder (OCD). A total of 12 abstracts were retrieved including prospective comparative and prospective uncontrolled studies, systematic reviews with and without meta-analyses, cost analyses, a pilot study, and a review article. Limitations of the studies included small patient populations, short-term follow-ups and heterogeneity of target strictures that underwent implantation. Overall, authors agreed that additional studies are needed to support the clinical role of DBS for OCD.

Alonso et al. (2015) conducted a systematic review and meta-analysis to evaluate CDBS for the treatment of obsessive-compulsive disorder. Thirty-one studies (n=116) with small patient populations (n=1–16) met inclusion criteria. Subjects were implanted in striatal areas—anterior limb of the internal capsule, ventral capsule and ventral striatum, nucleus accumbens and ventral caudate (n=83), the subthalamic nucleus (n=27) and in the inferior thalamic peduncle (n=6). Ages ranged from 18–75 years and subjects had a diagnosis of OCD according to the Diagnostic and Statistical Manual of Mental Disorders IV or International Classification of Diseases criteria. Included studies assessed the efficacy of CDBS on OCD according to changes on the Yale-Brown Obsessive Compulsive Scale (Y-BOCS) scores (13 studies; n=66) or percentage of responders defined by standardized criteria. Global percentage of Y-BOCS reduction was estimated at 45.1% and global percentage of responders at 60.0%. Data on quality of life was available on 29 patients and various outcome measures were used. No significant differences were detected in efficacy between implant targets. Five patients were lost to follow up. A total of 161 adverse effects were reported and most were considered mild, transient and reversible. Limitations of the studies included: the small patient populations; lack of a comparator; heterogeneity of outcome measures for QOL; heterogeneity of anatomical targeting, electrode design and stimulation parameters; and short duration of sham periods (minutes to three months). The authors also noted that information on OCD symptom dimension, which emerged as one of the clinical predictors of response, was not assessed using specifically designed tools in any study even though it was available for 95 patients. Due to the small number of patients meta-analysis could not be conducted. Clinical predictors of response, response rates and patient selection criteria need to be established.
Kisely et al. (2014) conducted a systematic review and meta-analysis of double-blind randomized controlled trials of CDBS vs. sham for the treatment of psychiatric conditions (e.g., OCD, major depression, anorexia nervosa). Five studies met inclusion criteria and all investigated CDBS for the treatment of OCD. Data analysis was done on 44 patients. The main outcome was a reduction in obsessive symptoms as measured by the Yale-Brown Obsessive Compulsive Scale (YBOCS). Duration of treatment ranged from 2–12 weeks. Patients treated with CDBS had a significantly lower mean score (p<0.001), representing partial remission, but one-third of the patients (n=16) experienced significant adverse effects (e.g., intracerebral hemorrhage, infection) There were no differences between the two groups in terms of other outcomes. Two studies reported outcomes for depression and anxiety in OCD patients and no statistically significant differences were seen between CDBS and sham (p=0.09). Limitations of the studies included the small patient populations (n=4–16), use of different CDBS target areas in the brain, and short duration of treatment (2–12 weeks). Because all of the subjects had severe treatment-resistant OCD, the result cannot be generalized to patient with less severe symptoms. Meta-analysis could not be conducted. CDBS remains an experimental treatment in adults for severe, medically refractory psychiatric conditions.

Kohl et al. (2014) conducted a systematic review to identify and evaluate the effectiveness of different targeted structures in the brain for deep brain stimulation for the treatment of obsessive-compulsive disorder. A total of 25 studies (n=109) that reported five brain stimulation targets met inclusion criteria. Targeted structures included: anterior limb of the internal capsule (n=14), nucleus accumbens (n=37), ventral capsule/ventral striatum (n=29), subthalamic nucleus (n=23) and inferior thalamic peduncle (N=6). Studies were primarily in the form of case reports or small case series (n=3–16). With the exception of one study with a follow-up of 51 months, follow-ups were less than 36 months. Eleven studies had a follow-up of one year or less. Some studies had overlapping patients (n=27). Results were similar regardless of the targeted structure, no superior structure was identified. Some studies reported improvement in symptoms but must be viewed with caution due to the poor methodology of the studies, small patient populations, short-term follow-ups and lack of a comparator.

A multicenter randomized controlled trial by Mallet et al. (2008) compared stimulation of the subthalamic nucleus to sham stimulation in 16 patients, age range 18–60 years, with a primary diagnosis of OCD. Patients were unresponsive to pharmacotherapy (e.g., at least three serotonin-reuptake inhibitors) and cognitive behavioral therapy. The on-off group underwent CDBS stimulation followed by sham stimulation and the off-on group underwent sham stimulation followed by CDBS stimulation. The stimulation periods involved two 3-month phases (i.e., month 3 to month 6 and month 7 to month 10) separated by a 1-month washout phase. Patients received medications during the trial. Following CDBS, a significant decrease was seen in the Yale-Brown Obsessive-Compulsive Scale (Y-BOCS) score (p=0.01). The on-off group had a significantly larger treatment effect than the off-on group (p=0.06). The Global Assessment of Functioning (GAF) score and the Clinical Global Impression (CGI) score were significantly improved after CDBS compared to sham (p=0.005, p=0.008, respectively). At the end of the first three months, six (75%) patients were responders based on the Y-BOCS score and eight (100%) were responders based on the GAF scores compared to three (38%) responders following sham. No significant differences following CDBS or sham were seen in the scores on the Montgomery and Asberg Depression Scale (MADRS), the Brief Scale for Anxiety, and the Sheehan Disability Scale. Due to the adverse events (i.e., intracerebral hemorrhage, infections requiring removal of the electrode) the authors stated that the benefits should be weighed carefully against the risks. Author-noted limitations included the variable deep brain stimulation settings used, small patient population and short duration of the study.

The American Society for Stereotactic and Functional Neurosurgery and the Congress of Neurological Surgeons (CNS) and Endorsed by the CNS and American Association of Neurological Surgeons (Hamani, et al. 2015) conducted a systematic review of the literature to develop guidelines for CDBS for OCD. Six studies met inclusion criteria. The authors reported the following regarding the treatment of medically refractory OCD: (1) one study (n=16) supported bilateral subthalamic nucleus CDBS; (2) one study (n=14) supported bilateral nucleus accumbens CDBS and one study (n=10) reported no difference in CDBS on/off scores; (3) evidence was insufficient to support unilateral CDBS. It was noted that the most effective target for CDBS, patient selection criteria and predictors for the best prognosis have not been established.

In their practice guideline for the treatment of OCD, the American Psychiatric Association (2013) described CDBS as a “less-well-supported” monotherapy that may be considered after first and second-line therapies have been exhausted but clarify that there is little supporting evidence (e.g., few small trials or case reports or
uncontrolled case series). CDBS has been reported to show efficacy in individuals with severe, highly treatment-resistant OCD, but the procedure is not without its risk.

**Tardive Dyskinesia:** Tardive dyskinesia is a neurological syndrome characterized by repetitive, involuntary, purposeless movements and caused by the long-term use of neuroleptic drugs. Additional features may include grimacing; tongue protrusion; lip smacking, puckering and pursing; rapid eye blinking; and rapid movements of the arms, legs, and trunk.

In a prospective phase two multicenter study, Damier et al. (2007) investigated CDBS in patients with severe TD refractory to medical management (n=10). Patients had been treated with antipsychotic medication for depression, schizophrenia or childhood disintegrative disorder. At the six-month follow-up, a double-blind evaluation resulted in successful outcomes by a decrease in the Extrapyramidal Symptoms Rating Scale, including choreic movements and dystonia score, by more than 40% (p=0.05). A significant decrease in the Abnormal Involuntary Movement Scale score (p=0.006) was also reported.

**Tourette Syndrome (Tics):** Tourette syndrome (TS), also known as chronic motor tic, chronic multiple tics, Gilles de la Tourette's disease or syndrome (GTS), habit spasms, maladie de tics, and paullitis tics, is a chronic neuropsychiatric disordered characterized by motor (e.g., repetitive involuntary movements of the face, head, upper body) and phonic, or vocal (e.g., sniffing, grunting, barking) tics. TS is often associated with behavioral abnormalities such as attention-deficit hyperactivity disorder and OCD. The waxing and waning characteristics of tics makes it difficult to investigate the safety and efficacy of CDBS. It has been proposed for patients who have not received adequate benefit from behavioral therapy and pharmacotherapy. Current studies include small patient populations, and the optimal CDBS target for these individuals has not been defined. Studies have primarily been in the form of case reports and case series with small patient populations and short-term follow-ups. The overall body of evidence agrees that there is insufficient evidence to support CDBS for the treatment of Tourette’s syndrome (Welter, et al., 2017; Naestrom et al., 2016; Servello, et al., 2016; Zhang, et al., 2016; Cannon, et al., 2012; Kuhn, et al., 2010; Ackermans, et al., 2008; Mink, et al., 2006).

The American Academy of Neurology (AAN) (Pringsheim et al., 2019) conducted a systematic literature review and developed practice guideline recommendations on the assessment and management of tics in people with Tourette syndrome and chronic tic disorders. AAN acknowledged there is limited information from randomized clinical trials for analysis and interpretation and there is no consensus on the optimal brain target for the treatment of tics. The recommendations regarding deep brain stimulation (DBS) stated a multidisciplinary evaluation should be completed including a mental health professional, confirmation of diagnosis and medication failure over multiple classes of medications and then DBS may be considered for severe, treatment-refractory, and self-injurious tics.

Baldermann et al. (2016) conducted a systematic review and meta-analysis of CDBS for Tourette syndrome (TS). Fifty-seven studies (n=156) and data from 48 of those studies (case reports and case series) were pooled for analysis. The Yale Global Tic Severity Scale (YGTSS) was the primary outcome measure. Secondary outcome measures included subscores of the YGTSS (Impairment, Tic Severity comprising motor tics and vocal tics), modified Rush Videobased Tic Rating Scale (mRVRS). If available, values of the Beck Depression Inventory (BDI) and the Yale-Brown Obsessive Compulsive Scale (Y-BOCS) were assessed. Overall, CDBS resulted in a significant median improvement of 52.68% (n=156; p<0.001) for the Global YGTSS at last available follow-up, median improvement rates of 48% for tic severity (n=73; p<0.001) and significant improvement in the mRVRS (n=27; p<0.001). Motor tics decreased by a median of 38.56% (n=71; p<0.001) and vocal tics by 40% (n=70; p<0.001). Comparing reduction rates of motor and vocal tics revealed a significantly higher mean tic reduction was seen for vocal tic vs. motor tic (p=0.012). The authors noted that the outcome varied across the sample, with some patients experiencing complete remission and others showing no improvement at all and the evidence was of low quality. Other limitations include the small patient populations, nine studies did not use the YGTSS, and the lack of randomized controlled studies. Well-designed randomized controlled trials and identification of effective target points are needed to support CDBS for the treatment of TS.

Piedad et al. (2012) conducted a systematic review to determine which patients with Tourette syndrome (TS) should be treated with CDBS and the best target areas for electrode placement. Thirty-six studies met inclusion criteria including case reports, three case series and three randomized controlled trial. Based on the available
data, the authors noted that it was “suggested” that the best candidates are patients with significant functional impairment due to tic symptoms and are nonresponsive to conventional pharmacotherapy and behavioral interventions. The globus pallidus internus and thalamus appeared to be the safest and most effective targets, especially for patients with “pure” TS and patients with comorbid obsessive-compulsive symptoms, anxiety and depression. There is a lack of consensus on treatment-refractoriness and large randomized controlled trials are needed to establish patient selection criteria and the appropriate target areas for placement.

The European Society for the Study of Tourette Syndrome (ESSTS) (Muller-Vahl, et al, 2011) conducted a systematic review of the literature to evaluate CDBS for the treatment of Tourette syndrome (TS). Twenty four studies (n=63) including three randomized controlled trials, 18 case reports and three case series were reviewed. ESSTS concluded that CDBS should only be used in “treatment resistant and severely affected adults” and “highly” recommended that it be in the context of controlled clinical trials.

The Tourette Syndrome Association (Mink, et al., 2007) convened a group of TS and CDBS experts to develop guidelines for the early use and potential clinical trials of CDBS for the treatment of TS believing that investigation of CDBS for TS was justified due to the success of CDBS with other disorders. The subgroup stated that although CDBS has the potential to be an effective therapy for a carefully selected subgroup of TS patient’s “there are many unknowns about the potential applications” of CDBS and investigation is warranted.

**Directional Deep Brain Stimulation**

It has been proposed that a deep brain stimulation system that uses a directional lead (directional deep brain stimulation [DDBS]) has the potential to more accurately target and precisely control stimulation improving the effectiveness of DBS while avoiding unwanted side effects. These systems are being investigated for the treatment of Parkinson’s disease and essential tremor. Currently, available directional lead systems use different types of stimulation. One uses a single current source and the other uses a multiple independent current source. Directional leads have the potential to allow for the minimum current necessary for stimulation which is unknown with conventional DBS systems. Directional leads are proposed to provide a reduction in electrode size and reduce the electrode surface area. The ability to steer electrical current may result in a reduction of activated tissue volume, improving clinical efficacy of deep brain stimulation by reaching the expected beneficial effects at a lower current. In addition, directional leads could potentially increase the current threshold at which side effects appear. Challenges with a directional lead include anatomical targeting and the ability and time to search for the best parameter settings. Programming strategies and guidelines need to be established. Which patients will benefit from directional DBS vs. conventional DBS is unknown. Dembek et al. 2017 noted that an important aspect of directional DBS, which is yet to be investigated, is battery consumption. Directional electrodes have considerably higher impedances and it is difficult to estimate the battery drain which also depends on the technical properties of the battery and pulse generator (Dembek, et al., 2017; Schupack, et al., 2017; Pollo, et al., 2014).

The St. Jude Medical Infinity™ DBS system is the first FDA approved system to feature a directional lead, designed to deliver electrical current to a specific target in the brain and therefore, proposed to minimize unwanted side effects from brain stimulation to non-targeted areas. Conventional deep brain stimulation is traditionally performed using four-contact cylindrical leads that provide a relatively uniform current spread in all directions (omnidirectional) including areas that may result in unwanted side effects. The Infinity directional lead has eight independent electrode contacts distributed throughout the lead. Each electrode can be turned on or off to facilitate the desired stimulation direction, shape and length for targeting and adjustment as needed. According to the manufacturer, the system is the first DBS system to use a wireless iOS™ platform (an Apple mobile operating system). An iPad mini™ (Apple, Inc.) clinician programmer is used by the physician for programming of the device, and patients use an iPad Touch® (Apple, Inc.) controller for symptom control. The system is proposed for the treatment of Parkinson’s disease or essential tremor and can be upgraded without surgical intervention.

**U.S. Food and Drug Administration:** On September 19, 2016, the St. Jude Medical Infinity™ DBS system was FDA approved as a supplement to an earlier Premarket Approval (PMA) for the St. Jude Medical Brio Neurostimulation system. This approval was for a change in design, components, specifications, and material. The most recent supplemental approval pertaining to the Infinity neurostimulation system was issued on May 1,
2017, and was for a firmware update. According to the manufacturer, the Infinity DBS System is indicated for "bilateral stimulation of the subthalamic nucleus (STN) as an adjunctive therapy to reduce some of the symptoms of advanced levodopa-responsive Parkinson's disease that are not adequately controlled by medications, and unilateral or bilateral stimulation of the ventral intermediate nucleus (VIM) of the thalamus for the suppression of disabling upper extremity tremor in adult essential tremor patients whose tremor is not adequately controlled by medications and where the tremor constitutes a significant functional disability" (FDA; 2016; St. Jude, 2016).

Literature Review:
There is insufficient evidence in the published peer-reviewed literature to support the safety and effectiveness of directional DBS including the Infinity DBS system. Published studies have primarily been in the form of pilot/feasibility studies with small patient populations (n=7-11) investigating the use of different types of directional leads for the treatment of Parkinson disease. Some studies investigated intraoperative placement or seven-day postoperative follow-up. Most studies used devices that are not FDA approved. One study reported on 3-6 month follow-ups (n=7) using a non-FDA approved device (Dembek, et al., 2017; Bour, et al., 2015; Contarino, et al., 2014; Pollo, et al., 2014).

In a clinical research response Hayes (2017) stated that a comprehensive literature search failed to locate any peer-reviewed studies evaluating the Infinity DBS system. There are currently multiple active trials evaluating the safety and efficacy of the Infinity system.

Responsive Cortical Stimulation

Closed-loop, responsive cortical stimulation involves the implantation of electrodes which are connected to a generator that provides electrical stimulation to specific areas of the brain in response to abnormal brain activity. This technology is different from an open-loop or nonresponsive technique (e.g. deep brain stimulation) which delivers a continuous or intermittent electrical stimulation at programmed intervals. Closed-loop, responsive cortical stimulation is supported by the published peer-reviewed literature as an adjunctive treatment option for a carefully identified subpopulation of patients with medically refractory partial epilepsy who are not candidates for surgery or for vagal nerve stimulation (Heck, et al., 2014; Fridley et al., 2012; Morrell, et al., 2011; Skarpaas and Morrell, 2009).

Epileptic seizures are classified as partial or generalized depending on whether they begin focally at one or two points in the brain (i.e., a partial-onset seizure) or bilaterally with multiple foci (i.e., a generalized seizure). Standard therapy includes antiepileptic medication, vagal nerve stimulator and/or surgical removal of seizure focus. Partial seizures can generalize secondarily and result in tonic-clonic activity in which the person loses consciousness accompanied by muscle stiffness and jerking movements. In a subset of patients with medically refractory partial epilepsy, electrical cortical stimulation has been proposed as an adjunctive therapy to pharmacotherapy.

The RNS® System (NeuroPace, Inc. Mountain View, CA) is a responsive cortical stimulation closed-loop system. It is proposed as a treatment option for patients who have medically refractory partial epilepsy with partial onset seizures, are refractory to two or more antiepileptic medications and have one of the following seizure types: 1) simple partial motor: seizures characterized by alteration in motor function without change in awareness; 2) complex partial: seizure includes impairment in awareness and/or 3) generalized tonic, clonic or tonic-clonic seizures. RNS is not indicated for the treatment of generalized epilepsies in which seizures arise from all areas of the brain at the same time.

The system includes an implantable RNS® neurostimulator, a Depth Lead (implanted within the brain) and a NeuroPace® Cortical Strip Lead (implanted on the brain surface). Each lead contains four electrodes. The leads to be implanted are selected based on the location of the seizure focus: subdural cortical, depth, or a combination of the two. The Cortical Strip Leads are recommended for seizure onsets on the surface of the cortex, where the lead can be placed over the focus. The Cortical Strip Leads come in three lengths and are implanted through a craniotomy. The Depth Leads are recommended for seizure onsets beneath the cortical surface (e.g., within the mesial temporal lobe, within subcortical lesions) where the lead can be placed within the seizure focus. Depth Leads come in four different configurations. These leads may be implanted using stereotactic techniques through a burr hole in the skull. The leads are placed at the seizure focus as determined
by radiologic imaging, presurgical electroencephalogram (EEG) recordings, or phase II subdural electrocorticogram (ECoG) monitoring. The neurostimulator is a programmable, battery powered, microprocessor-controlled device that delivers a short train of electrical pulses to the brain through the implanted leads. The neurostimulator is implanted in the cranium flush with the skull, is extradural and does not come in contact the brain. Up to four leads may be implanted with only two leads connected to the neurostimulator at any given time. Once in place, the neurostimulator is covered by the scalp.

External components of the system include the programmer, laptop computer with software and a Wand that allows remote monitoring of brain activity. The Wand is used to retrieve stored data from the neurostimulator. Using the programmer, the physician programs the initial setting and makes follow-up adjustments as needed based on brain activity and response to stimulation. The typical patient receives brief bursts (100–200 msec) of high-frequency stimulation with a total cumulative stimulation time of less than six minutes a day. The programmer also allows visualization of the patient's brain electrical activity (electrocorticogram [ECoG]) in real-time and the ability to upload the patient's ECoGs stored in the RNS neurostimulator. The patient is provided a magnet that is swiped over the neurostimulator to record brain activity during a seizure. This activity enables the physician to identify the event during data review. The magnet can also be used to temporarily stop stimulation. The neurostimulator has to be replaced every 2.0–3.7 years when the battery reaches its end of service. If the existing leads are functioning properly and there are no problems, the same leads will be connected to the new stimulator. It is recommended that the leads not be removed if the stimulation is not successful due to potential damage to brain tissue.

U.S. Food and Drug Administration (FDA): The RNS System (NeuroPace, Inc. Mountain View, CA) is FDA approved by the premarket approval (PMA) application process. The device is indicated “as an adjunctive therapy in reducing the frequency of seizures in individuals 18 years of age or older with partial onset seizures who have undergone diagnostic testing that localized no more than two epileptogenic foci, are refractory to two or more antiepileptic medications, and currently have frequent and disabling seizures (motor partial seizures, complex partial seizures and/or secondarily generalized seizures). The RNS System has demonstrated safety and effectiveness in patients who average three or more disabling seizures per month over the three most recent months (with no month with fewer than two seizures), and has not been evaluated in patients with less frequent seizures”. Exclusion criteria in the FDA clinical trial included subjects who did not have an implanted vagus nerve stimulator or an implanted device that delivers electrical energy to the head, had not had surgery for the treatment of epilepsy within the preceding six month, and had not been diagnosed with active psychosis, severe depression or suicidal ideation in the preceding year. If subject had a VNS, it must have been explanted (excluding leads) prior to or at the time of RNS implantation. VNS must have been discontinued for at least three months prior to enrollment (FDA, 2013).

Continued approval of the PMA was contingent upon the submission of yearly reports including model number, number of devices sold and distributed. Also, NeuroPace must conduct and report on a long-term treatment study to establish safety (adverse event rates) and effectiveness (average disabling seizure frequency) through seven years. Successful responder rate is defined as sustained ≥ 50% reduction in total disabling seizures from baseline. Quality of life will also be measured.

**Literature Review**

Studies in the form of randomized controlled trials and prospective case series have evaluated responsive cortical stimulation for the treatment of medically refractory partial epilepsy with partial onset seizures. Reduction in seizures ranged from 47%–60% and a responder rate of up to 59% was reported. One study reported a 50% or greater reduction in seizures with 16% of participant seizure free following implantation. Some subjects remained on antiseizure medication while up to 9% of responders had a reduction in pharmacotherapy or discontinuation of anticonvulsants. No significant cognitive declines were reported on neuropsychological outcome measures. Significant improvement in verbal learning was reported depending on the area of brain involved. Up to 44% of subjects reported a statistically significant improvement in quality of life (QOL) (p<0.001) and 16% reported a decline in QOL. The most common device related adverse events were implant site infection (< 9.0%) involving soft tissue and neurostimulator explantation (<5%) (Bergey, et al., 2015; Heck, et al., 2014; Loring, et al., 2015; Meador, et al., 2015; Morrell, et al., 2011).

**Motor Cortex Stimulation**
Motor cortex stimulation (MCS), also referred to as cerebral cortex stimulation or extradural motor cortex stimulation (EMCS), is primarily proposed for relief of refractory neuropathic pain and involves implantation of epidural electrodes in the cerebral cortex. Although the exact mechanism of MCS is unknown, it has been hypothesized that it may induce the release of endogenous opioids in various brain structures, resulting in pain relief (Cheng and Eskandar, 2010; Maarrawi, et al., 2007).

Typically, temporary placement of a MCS device is performed to determine if the device will relieve the pain. If the patient consistently (e.g., 3–14 days) experiences at least a 50% reduction in pain, a second surgery is performed to permanently connect the electrodes and implant the programmable device under the skin near the collarbone. Image-guided localization (e.g., magnetic resonance imaging [MRI], functional MRI [fMRI], computerized tomography) and intraoperative mapping using somatosensory evoked potential (SSEP), intraoperative stimulation of the cortex, and/or neuronavigation are used to locate the precise placement of the electrodes, which is critical for successful pain relief. Electrodes are introduced through a burr hole or frontoparietal craniotomy into the protective layer covering the motor cortex area (epidural) of the brain, placed over the targeted area and connected to a programmable pulse generator. The lead wire from the programmable device goes up the back of the neck under the scalp to the electrodes (Cheng and Eskandar, 2010; Levy, et al., 2010; Arle and Shils, 2008).

Because MCS is a less invasive procedure than other invasive surgical procedures such as CDBS, it is proposed to be a safer procedure with less serious complications. MCS has been proposed for treatment when invasive procedures have failed or when patients are not appropriate candidates for an invasive procedure. Some proponents of MCS report that MCS is less harmful than long-term opioid use. However, serious complications including intracranial bleeding; infection; permanent neurological deficits; and seizure activity, especially during programming and reprogramming of the MCS device have been reported (Cheng and Eskandar, 2010; Levy, et al., 2010; Maarrawi, et al., 2007).

MCS was initially used for the treatment of medically refractory central pain syndrome following ischemic or hemorrhagic stroke and facial neuralgias (e.g., trigeminal neuralgia, postsurgical trigeminal deafferentation such as anesthesia dolorosa, postherpetic neuralgia). However, its use has been proposed for the treatment of other conditions including: neuropathic pain following spinal cord injuries (e.g., supraspinal pain after hemorrhage and infarction), post-stroke pain, chronic pain, amyotrophic lateral sclerosis (ALS), thalamic pain syndrome, plexus avulsion, dysphagia, Parkinson disease, dystonia, spasticity, multiple sclerosis, chronic regional pain syndrome (CRPS), phantom limb pain, epilepsy, and peripheral nervous system lesions. MCS has also been used for intraoperative monitoring (Tanei, et al., 2011; Cheng and Eskandar, 2010; Levy, et al., 2010; Fontaine, et al., 2009; Prévinaire, et al., 2009; Arle and Shils, 2008).

U.S. Food and Drug Administration (FDA): There are no devices approved by the FDA for motor cortex stimulation.

Literature Review: There is insufficient evidence in the published peer-reviewed literature to support the safety and efficacy of MCS for any indication. Studies are primarily in the form of case reports and case series with small heterogeneous patient populations (n=3–10) and short-term follow-ups. Outcomes regarding the benefits of MCS are conflicting. Some studies reported that the initial pain relief following MCS was not sustained over time and in some cases, worsening of pain followed MCS. Surgical techniques, electrode placement, device programming, outcome measures and patient selection criteria have not been established.

Fontaine et al. (2009) conducted a systematic review to evaluate the safety and efficacy of MCS for the treatment of chronic neuropathic pain. Fourteen studies (n=210), case series and retrospective reviews, met inclusion criteria. Reported mean follow-up was 30.5 months (range, several weeks to ten years). Overall, 56.7% of patients reported a 40%–50% (good) improvement in pain. Sixty-nine patients with ≥ 1 year follow-up reported a good response, and in two studies with 49-month follow-up, 47% and 22.6% of patients reported good results. The reported Visual Analog Scale scores for 76 patients reflected an average 56.6% improvement in postoperative scores. The most common adverse events were intraoperative or trial stimulation period seizures, infections and hardware-related problems. The authors stated that these results should be viewed with caution due to the limited number of studies that were primarily retrospective study designs with heterogeneous small
patient populations (n=3–31). Short-term follow-up, loss of efficacy and the variable surgical techniques, stimulation settings and electrode placement were other noted limitations.

A limited number of randomized controlled trials have evaluated the use of MCS for the treatment of neuropathic pain comparing outcomes of on/off stimulation. In a crossover trial, Lefaucheur et al. (2009) reported that patients with trigeminal neuralgia (n=4), brachial plexus lesion (n=4), neurofibromatosis type-1 (n=3), upper limb amputation (n=2), herpes zoster ophthalmicus (n=1), atypical orofacial pain secondary to dental extraction (n=1), and traumatic nerve trunk transection in a lower limb (n=1) did not experience sustained pain relief during the crossover phase of the trial. Of the 12 patients who participated in the open study phase, 60% reported a mean pain relief of 48% on Visual Analog Scale scores at 12 months follow-up. In a study involving 11 patients (Velasco, et al., 2008) with chronic deafferentation pain syndromes (n=11), three patients reported no improvement following a temporary trial of MCS. The remaining patients who underwent permanent implantation reported a significant reduction in pain (p<0.01) during the one-year follow-up. The authors stated that “given the heterogeneous information that one gathers from the literature on MCS, it is impossible at present to draw a conclusion concerning candidates for this treatment.”

**Centers for Medicare & Medicaid Services (CMS)**

- National Coverage Determinations (NCDs): Deep Brain Stimulation for Essential Tremor and Parkinson’s Disease (160.24), last revised 2003. The Coverage Policy is generally consistent with NCD. Refer to the CMS NCD table of contents link in the reference section.
- Local Coverage Determinations (LCDs): No LCDs found.

**Use Outside of the US**

**Conventional deep brain stimulation (CDBS):** CDBS systems are approved for use in Europe.

The European Federation of Neurological Society and the Movement Disorder Society-European Section (EFNS/MDS-ES) (Albanese, et al., 2011) task force conducted a systematic literature review and published evidence-based recommendations for the diagnosis and treatment of dystonia. The recommendations stated that pallidal CDBS is a good option for primary generalized or segmental dystonia and cervical dystonia following failure of medication or botulinum toxin. In general, pallidal CDBS is less effective in secondary dystonia with the exception of tardive dystonia.

In their guidelines on neurostimulation for neuropathic pain, the European Federation of Neurological Societies (EFNS) (Cruccu, et al., 2007) stated that the literature primarily consisted of case series including patients with central post-stroke pain (CPSP) (n=20 case series with much overlap; 143 non-overlapping patients) and facial neuropathic pain (n=8 case series; 60 patients). Success rates ranged from 0%–100% for CPSP and 43%–100% for facial pain. Most studies did not have comparators, and outcome and treatment assessments were dissociated. Only case reports were found on patients with phantom pain, brachial plexus, nerve trunk lesion, spinal cord lesions and complex regional pain syndrome (CRPS). Based on these studies, EFNS stated that “MCS is useful in 50–60% of patients with CPSP and central or peripheral facial neuropathic pain, with small risk of medical complications,” but the evidence was insufficient to support MCS for any other condition.

The National Institute for Health and Clinical Excellence (NICE) (United Kingdom) 2017 guidance on the management of Parkinson’s disease in adults stated that DBS should not be offered to people with PD whose symptoms are adequately controlled with medical therapy. DBS can be considered for people with advanced Parkinson’s disease whose symptoms are not adequately controlled by best medical therapy.

In a guidance document for Conventional DBS for dystonia, the National Institute for Health and Clinical Excellence (NICE) (United Kingdom) (2006a) stated that the current evidence supports the safety and efficacy of CDBS as a treatment modality for dystonia. Dystonia may be treated conservatively or surgically. Conservative treatment only treats the symptoms, and surgical intervention (i.e., thalamotomy and pallidotomy) may not render long-term benefits.

**Directional deep brain stimulation:** The Vercise™ DBS system (Boston Scientific, Valencia, CA) with a directional lead received CE Mark approval in June 2017. The Vercise DBS system is a 16-output, multiple-
channel, constant-current, implantable pulse generator with a rechargeable battery. The system is proposed to allow steerable axial shaping of the electrical stimulation field, with adjustment of current on every contact. As noted above, there is insufficient evidence in the published peer-reviewed literature to support the safety and efficacy of the directional deep brain stimulation systems. Studies have primarily been in the form of pilot/feasibility studies with small patient populations (n=7-11) and short-term follow-ups (Dembek, et al., 2017; Bour, et al., 2015; Contarino, et al., 2014; Pollo, et al., 2014).

Timmermann et al. (2015) conducted a prospective, multicenter, non-randomized (n=53), premarket study to evaluate the safety and effectiveness of the Vercise for bilateral stimulation of the subthalamic nucleus for the treatment of moderate-to-severe idiopathic Parkinson’s disease. The study, called Vercise Implantable Stimulator for Treating Parkinson’ Disease (VANTAGE), was conducted at six centers in six European countries. Inclusion criteria were those patients who were ages 21–75 years, had bilateral idiopathic Parkinson’s disease with motor symptoms for more than five years, had a Hoehn and Yahr score of ≥2, and had a Unified Parkinson’s disease rating scale part III (UPDRS III) score in the medication-off state of more than 30, which improved by 33% or more after a levodopa challenge. The primary endpoint was the mean change in UPDRS III scores. Of the 53 patients enrolled in the study, 40 patients, aged 42–75 years, who had symptoms of PD for 3–22 years received a bilateral implant in the subthalamic nucleus. Follow-up occurred at 12, 26, and 52 weeks following implant. Compared to baseline, improvement was reported in the UPDRS III motor score six months after the first lead implantation with a significant mean difference of 23.8 (p<0·0001) and remained stable up to week 52. A total of 125 adverse events were reported. Dystonia, speech disorder, and apathy were the most common adverse events. Three serious adverse events (infection, migration and respiratory depression) were attributed to the device but resolved without residual effects and stimulation remained on. At week 52, symptoms were rated as improved on the global impression of change scale by 35/39 patients (90%) and by 38/39 treating clinicians (97%). The intake of antiparkinsonian drugs, measured by levodopa equivalent dose, fell significantly from baseline to week 52. Limitations of the study include: small patient population; 13 patients did not enter or complete the study; after the first ten patients, the DBS lead was modified; patients with <5 years of symptoms were included; 160 protocol deviations were recorded; lack of randomization and blinding of patients and clinicians; and patient self-rated improvement in symptoms on the global impression of change scale. The Vercise DBS system is not FDA approved for use in the United States.

## Coding/Billing Information

Note: 1) This list of codes may not be all-inclusive.
2) Deleted codes and codes which are not effective at the time the service is rendered may not be eligible for reimbursement.

### Conventional Deep Brain Stimulation

Considered Medically Necessary when criteria in the applicable policy statements listed above are met:

<table>
<thead>
<tr>
<th>CPT® Codes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>61863</td>
<td>Twist drill, burr hole, craniotomy, or craniectomy with stereotactic implantation of neurostimulator electrode array in subcortical site (eg, thalamus, globus pallidus, subthalamic nucleus, periventricular, periaqueductal gray), without use of intraoperative microelectrode recording; first array</td>
</tr>
<tr>
<td>61864</td>
<td>Twist drill, burr hole, craniotomy, or craniectomy with stereotactic implantation of neurostimulator electrode array in subcortical site (eg, thalamus, globus pallidus, subthalamic nucleus, periventricular, periaqueductal gray), without use of intraoperative microelectrode recording; each additional array (List separately in addition to primary procedure)</td>
</tr>
<tr>
<td>61867</td>
<td>Twist drill, burr hole, craniotomy, or craniectomy with stereotactic implantation of neurostimulator electrode array in subcortical site (eg, thalamus, globus pallidus, subthalamic nucleus, periventricular, periaqueductal gray), with use of intraoperative microelectrode recording; first array</td>
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<td>Code</td>
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<tr>
<td>61868</td>
<td>Twist drill, burr hole, craniotomy, or craniectomy with stereotactic implantation of neurostimulator electrode array in subcortical site (eg, thalamus, globus pallidus, subthalamic nucleus, periventricular, periaqueductal gray), with use of intraoperative microelectrode recording; each additional array (List separately in addition to primary procedure)</td>
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<tr>
<td>61880</td>
<td>Revision or removal of intracranial neurostimulator electrodes</td>
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<tr>
<td>61885</td>
<td>Insertion or replacement of cranial neurostimulator pulse generator or receiver, direct or inductive coupling; with connection to a single electrode array</td>
</tr>
<tr>
<td>61886</td>
<td>Insertion or replacement of cranial neurostimulator pulse generator or receiver, direct or inductive coupling; with connection to 2 or more electrode arrays</td>
</tr>
<tr>
<td>61888</td>
<td>Revision or removal of cranial neurostimulator pulse generator or receiver</td>
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**HCPCS Codes**

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<th>Code</th>
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<td>C1767</td>
<td>Generator, neurostimulator (implantable), nonrechargeable</td>
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<td>C1778</td>
<td>Lead, neurostimulator (implantable)</td>
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<td>C1787</td>
<td>Patient programmer, neurostimulator</td>
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<tr>
<td>C1816</td>
<td>Receiver and/or transmitter, neurostimulator (implantable)</td>
</tr>
<tr>
<td>C1822</td>
<td>Generator, neurostimulator (implantable), high frequency, with rechargeable battery and charging system</td>
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<tr>
<td>C1883</td>
<td>Adaptor/extension, pacing lead or neurostimulator lead (implantable)</td>
</tr>
<tr>
<td>C1897</td>
<td>Lead, neurostimulator test kit (implantable)</td>
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<tr>
<td>L8679</td>
<td>Implantable neurostimulator, pulse generator, any type</td>
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<tr>
<td>L8680</td>
<td>Implantable neurostimulator electrode, each</td>
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<tr>
<td>L8681</td>
<td>Patient programmer (external) for use with implantable programmable neurostimulator pulse generator, replacement only</td>
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<tr>
<td>L8682</td>
<td>Implantable neurostimulator radiofrequency receiver</td>
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<td>L8683</td>
<td>Radiofrequency transmitter (external) for use with implantable neurostimulator radiofrequency receiver</td>
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<td>L8685</td>
<td>Implantable neurostimulator pulse generator, single array, rechargeable, includes extension</td>
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<tr>
<td>L8686</td>
<td>Implantable neurostimulator pulse generator, single array, non-rechargeable, includes extension</td>
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<tr>
<td>L8687</td>
<td>Implantable neurostimulator pulse generator, dual array, rechargeable, includes extension</td>
</tr>
<tr>
<td>L8688</td>
<td>Implantable neurostimulator pulse generator, dual array, non-rechargeable, includes extension</td>
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</table>

**Directional Deep Brain Stimulations (e.g., Infinity™ CDBS System)**

Considered Experimental/Investigational/Unproven:

<table>
<thead>
<tr>
<th>CPT® Codes</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>61863</td>
<td>Twist drill, burr hole, craniotomy, or craniectomy with stereotactic implantation of neurostimulator electrode array in subcortical site (eg, thalamus, globus pallidus, subthalamic nucleus, periventricular, periaqueductal gray), without use of intraoperative microelectrode recording; first array</td>
</tr>
<tr>
<td>61864</td>
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</tr>
<tr>
<td>61867</td>
<td>Twist drill, burr hole, craniotomy, or craniectomy with stereotactic implantation of neurostimulator electrode array in subcortical site (eg, thalamus, globus pallidus, subthalamic nucleus, periventricular, periaqueductal gray), with use of intraoperative microelectrode recording; first array</td>
</tr>
<tr>
<td>61868</td>
<td>Twist drill, burr hole, craniotomy, or craniectomy with stereotactic implantation of neurostimulator electrode array in subcortical site (eg, thalamus, globus pallidus,</td>
</tr>
</tbody>
</table>
Responsive Cortical Stimulation

Considered Medically Necessary when criteria in the applicable policy statements listed above are met:

<table>
<thead>
<tr>
<th>CPT® Codes</th>
<th>Description</th>
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</thead>
<tbody>
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<td>61850</td>
<td>Twist drill or burr hole(s) for implantation of neurostimulator electrodes, cortical</td>
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<tr>
<td>61860</td>
<td>Cranietomy or craniotomy for implantation of neurostimulator electrodes, cerebral, cortical</td>
</tr>
<tr>
<td>61863</td>
<td>Twist drill, burr hole, craniotomy, or craniectomy with stereotactic implantation of neurostimulator electrode array in subcortical site (e.g., thalamus, globus pallidus, subthalamic nucleus, periventricular, periaqueductal gray), without use of intraoperative microelectrode recording; first array</td>
</tr>
<tr>
<td>61864</td>
<td>Twist drill, burr hole, craniotomy, or craniectomy with stereotactic implantation of neurostimulator electrode array in subcortical site (e.g., thalamus, globus pallidus, subthalamic nucleus, periventricular, periaqueductal gray), without use of intraoperative microelectrode recording; each additional array (List separately in addition to primary procedure)</td>
</tr>
<tr>
<td>61880</td>
<td>Revision or removal of intracranial neurostimulator electrodes</td>
</tr>
<tr>
<td>61885</td>
<td>Insertion or replacement of cranial neurostimulator pulse generator or receiver, direct or inductive coupling; with connection to a single electrode array</td>
</tr>
<tr>
<td>61886</td>
<td>Insertion or replacement of cranial neurostimulator pulse generator or receiver, direct or inductive coupling; with connection to 2 or more electrode arrays</td>
</tr>
<tr>
<td>61888</td>
<td>Revision or removal of cranial neurostimulator pulse generator or receiver</td>
</tr>
</tbody>
</table>

**HCPCS Codes**

- C1767: Generator, neurostimulator (implantable), nonrechargeable
- C1778: Lead, neurostimulator (implantable)
- C1787: Patient programmer, neurostimulator
- C1816: Receiver and/or transmitter, neurostimulator (implantable)
- C1883: Adaptor/extension, pacing lead or neurostimulator lead (implantable)
- C1897: Lead, neurostimulator test kit (implantable)
L8679  Implantable neurostimulator, pulse generator, any type
L8680  Implantable neurostimulator electrode, each
L8681  Patient programmer (external) for use with implantable programmable neurostimulator pulse generator, replacement only
L8686  Implantable neurostimulator pulse generator, single array, non-rechargeable, includes extension
L8688  Implantable neurostimulator pulse generator, dual array, non-rechargeable, includes extension

Motor Cortex Stimulation

Considered Experimental/Investigational/Unproven when used to report motor cortex stimulation:

<table>
<thead>
<tr>
<th>CPT® Codes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>61850</td>
<td>Twist drill or burr hole(s) for implantation of neurostimulator electrodes, cortical</td>
</tr>
<tr>
<td>61860</td>
<td>Craniectomy or craniotomy for implantation of neurostimulator electrodes, cerebral, cortical</td>
</tr>
<tr>
<td>61880</td>
<td>Revision or removal of intracranial neurostimulator electrodes</td>
</tr>
<tr>
<td>61885</td>
<td>Insertion or replacement of cranial neurostimulator pulse generator or receiver, direct or inductive coupling; with connection to a single electrode array</td>
</tr>
<tr>
<td>61886</td>
<td>Insertion or replacement of cranial neurostimulator pulse generator or receiver, direct or inductive coupling; with connection to 2 or more electrode arrays</td>
</tr>
<tr>
<td>61888</td>
<td>Revision or removal of cranial neurostimulator pulse generator or receiver</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HCPCS Codes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1767</td>
<td>Generator, neurostimulator (implantable), nonrechargeable</td>
</tr>
<tr>
<td>C1778</td>
<td>Lead, neurostimulator (implantable)</td>
</tr>
<tr>
<td>C1787</td>
<td>Patient programmer, neurostimulator</td>
</tr>
<tr>
<td>C1816</td>
<td>Receiver and/or transmitter, neurostimulator (implantable)</td>
</tr>
<tr>
<td>C1820</td>
<td>Generator, neurostimulator (implantable), with rechargeable battery and charging system</td>
</tr>
<tr>
<td>C1822</td>
<td>Generator, neurostimulator (implantable), high frequency, with rechargeable battery and charging system</td>
</tr>
<tr>
<td>C1883</td>
<td>Adaptor/extension, pacing lead or neurostimulator lead (implantable)</td>
</tr>
<tr>
<td>C1897</td>
<td>Lead, neurostimulator test kit (implantable)</td>
</tr>
<tr>
<td>L8679</td>
<td>Implantable neurostimulator, pulse generator, any type</td>
</tr>
<tr>
<td>L8680</td>
<td>Implantable neurostimulator electrode, each</td>
</tr>
<tr>
<td>L8681</td>
<td>Patient programmer (external) for use with implantable programmable neurostimulator pulse generator, replacement only</td>
</tr>
<tr>
<td>L8682</td>
<td>Implantable neurostimulator radiofrequency receiver</td>
</tr>
<tr>
<td>L8683</td>
<td>Radiofrequency transmitter (external) for use with implantable neurostimulator radiofrequency receiver</td>
</tr>
<tr>
<td>L8685</td>
<td>Implantable neurostimulator pulse generator, single array, rechargeable, includes extension</td>
</tr>
<tr>
<td>L8686</td>
<td>Implantable neurostimulator pulse generator, single array, non-rechargeable, includes extension</td>
</tr>
<tr>
<td>L8687</td>
<td>Implantable neurostimulator pulse generator, dual array, rechargeable, includes extension</td>
</tr>
<tr>
<td>L8688</td>
<td>Implantable neurostimulator pulse generator, dual array, non-rechargeable, includes extension</td>
</tr>
</tbody>
</table>

Table adapted from the Centre for Evidence Based Medicine, University of Oxford, March 2009

References


139. Salanova V. Deep brain stimulation for epilepsy. Epilepsy Behav. 2018 Jul 17. [Epub ahead of print].


164. Tarsy D. Device-assisted and surgical treatments for Parkinson disease. In: Up to Date, Hurtig HI (Ed), UpToDate, Waltham, MA. Accessed Sept 23, 2019


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