DEEP BRAIN STIMULATION FOR PARKINSON'S DISEASE

DUBOKA STIMULACIJA MOZGA KOD PARKINSONOVE BOLESTI

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ABSTRACT

Introduction: Surgeons first became interested in Parkinson's disease in the early part of the 20th century when surgical attempts were made to control the tremor of Parkinson's disease. The "Golden Age" of surgery for Parkinson's disease was in the 1950's and 1960's when stereotactic frames were available and very precise lesions within the basal ganglia could be accomplished with relative safety. Surgeons in Europe, North America and Asia all developed the field of "Functional and Stereotaxic Neurosurgery". Patients with tremor, which does not respond to medical management, who are medically stable, are candidates for thalamic deep brain stimulation. The tremor must be disabling and interfere with activities of daily living such as eating, dressing and writing.
Material and methods: The pre-operative evaluation of all Parkinsonian patients prior to bilateral subthalamic nucleus (STN) surgery includes neuropsychological testing to rule out dementia and extensive medical workup to be certain that the patients have adequate cardiorespiratory reserves to undergo the stressful period of the multiple surgical procedures. Our protocol, besides the above-mentioned testing, does include pre-operative videotaping of each patient in both the on and the off phase of their medication. We have chosen to use both MRI and CT scans for image guidance for our stereotactic procedures.
Results and Discussion: Despite this being a very rigorous surgical endeavor for the patients, the benefit has been quite worth the effort. In our series, 2/3 of the patients would report a very significant benefit while 1/3 have had minor benefit from the deep brain stimulation system for Parkinson's. Overall, we have seen a reduction in the need for Parkinsonian medications and a dramatic decrease in the incidence of dyskinesias in the patients who had them pre-operatively. After this initial programming period of 4-6 weeks, most patients reach a relative plateau with a lower dose of medicine and improved level of function. Gait has improved in almost all of the patients. There are two basic types of complications; those associated with surgery and those associated with stimulation itself. The surgical complication rate in our hands mirrors that of the existing literature.
Conclusion: Deep brain stimulation is technically challenging but offers a significant potential to improve the quality of life for patients with Parkinson's disease or disabling tremor.

Key words: Parkinson's disease, deep brain stimulation

APSTRAKT

Uvod: Hirurzi su se prvi put zainteresirali za Parkinsonovu bolest ranih godina dvadesetog stoljeća kada su hirurški pokušaji imali za cilj kontrolu tremora kod ove bolesti. „Zlatno doba" hirurgije u liječenju Parkinsonove bolesti bile su pedesete i šezdesete godine prošlog stoljeća kada su stereotaksijski okviri postali dostupni i na taj način postignuta relativna sigurnost u preciznom ciljanju lezija unutar bazalnih ganglija. Hirurzi u Evropi, Sjevernoj Americi i Aziji razvili su oblast „Funkcionalne i Stereotaksijske Neurohirurgije". Pacijenti sa tremorom koji ne reagiraju na medikamentozni tretman, koji su medicinski stabilni, kandidati su za stimulaciju talamusa. Tremor mora uzrokovati invalidnost i interferirati sa svakodnevnim životnim aktivnostima što su jedenje, oblačenje i pisanje.
Materijal i metode: Prije bilateralne operacije subtalamičkog jedra svih pacijenata sa Parkinsonovom bolešću podvrgavaju se neurofiziološkom testiranju demencije i detaljnom medicinskom ispitivanju da bi se odredile pacijentove kardiorespiratorne rezerve za stresan period multiplih hirurških procedura. Naš protokol, pored spomenutih testova uključuje preoperativno videosnimanje svakog pacijenta u fazama sa i bez njihove medikacije. Kao vodič za određivanje cilja tokom stereotaksijskih procedura koristili smo snimke MR i CT.

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Rezultati i Diskusija: Uprkos veoma rigoroznom hirurškom režimu za pacijente, korist koju su imali bila je vrednija od napora. U našim serijama, 2/3 pacijenata imali su značajno poboljšanje dok je 1/3 imala minimalno poboljšanje Parkinsonove bolesti nakon duboke stimulacije mozga. Primijetili smo ukupno smanjenje potreba za lijekovima kod Parkinsonove bolesti i dramatično smanjenje incidence diskinezije u pacijenata koji su je imali preoperativno. Nakon inicijalnog programiranja u periodu 4-6 sedmica, većina pacijenata dostiže relativan nivo sa nižim dozama lijekova i poboljšanim funkcionalnim nivoom. Hod je poboljšan u skoro svih pacijenata. Postoje dvije vrste komplikacija: one koje su udružene sa operacijom i one koje su udružene sa stimulacijom. Stopa naših hirurških komplikacija ista je kao u postojećoj literaturi.
Zaključak: Duboka stimulacija mozga predstavlja tehnički izazov, ali nudi značajan potencijal za poboljšanjem kvaliteta života u pacijenata sa Parkinsonovom bolešću ili teškim tremorom.

Ključne riječi: Parkinsonova bolest, duboka stimulacija mozga

INTRODUCTION

Parkinson's disease is a debilitating neurodegenerative disorder named after James Parkinson, a physician in London in the early 1800's. Dr. Parkinson wrote a very clear description of the disease, including the tremor, the slowness of movement, the rigidity and the ultimate hypokinesia[1]. Surgeons first became interested in Parkinson's disease in the early part of the 20th century when surgical attempts were made to control the tremor of Parkinson's disease. For the first half of the 20th century, these attempts consisted primarily of surgical ablative procedures done in an open fashion[2]. The success rates were not very good. For the most part, what was accomplished was a section of the pyramidal tract and a trade off of new weakness for a diminution in tremor. Side effects were common and the surgical morbidity and mortality were quite high. In the United States, seminal observations by Dr. Cooper revealed that the basal ganglia was an important area for control of movement and that lesions in the basal ganglia could be very effective in controlling some Parkinsonian symptoms[3]. Lesions in the basal ganglia were made using alcohol, freezing techniques and radiofrequency electrical current.

The "Golden Age" of surgery for Parkinson's disease was in the 1950's and 1960's when stereotactic frames were available and very precise lesions within the basal ganglia could be accomplished with relative safety. Surgeons in Europe, North America and Asia all developed the field of "Functional and Stereotaxic Neurosurgery"[4]. The thalamus, the globus pallidus and, even on occasion, the subthalamic nucleus were targeted. Surgeons discovered that there were differences in the symptom relief from the various lesions and also discovered during their intraoperative electrophysiology that stimulation, for example within the thalamus, could inhibit tremor. Surgery for Parkinson's disease came almost to a halt in the late 1960's and early 1970's after the introduction of L-Dopa in 1968[5]. The addition of Dopamine agonists soon thereafter and the improved medical management meant that fewer patients were referred for surgical management[6]. Unfortunately, over time the medical management of Parkinson's fails and increasingly Neurologists were seeing their patients develop disabling dyskinesias, as well as very severe motor fluctuations (on/off phenomenon). In the late 1980's, in order to address the dyskinesias, Dr. Lauri Laitenin in Scandinavia began to resurrect the operation known as pallidotomy with lesions in the globus pallidus interna. These lesions were very successful at relieving dyskinesia with variable success in helping bradykinesia and rigidity.

Chronic stimulation using electrical current within the brain had been performed from the time of the 1960's and 1970's being used almost exclusively for the treatment of intractable pain. The periaqueductal gray and occasionally the thalamus were stimulated with a variety of electrical parameters with some relief of pain. Unfortunately, the hardware proved to be fragile and the complication rate was significant. A neurosurgeon in Grenoble, France, Dr. Louis Benabid, recognized the potential of stimulation within the brain to treat tremor, by stimulation of the VIM nucleus of the thalamus, and stimulation of the subthalamic nucleus to treat all of the cardinal manifestations of Parkinson's disease[7]. The pioneering work of Dr. Benabid was followed up in the rest of Europe and in North America. In 1997, in the United States, chronic stimulation of

the VIM nucleus of the thalamus was approved by the Food and Drug Administration as a treatment for the tremor of Parkinson's disease and essential tremor[8,9]. Approval came a few years later for bilateral subthalamic nucleus stimulation for the treatment of all cardinal manifestations of Parkinson's disease [10, 11, 12]. Functional neurosurgery was making a comeback.

ORGANIZATION OF THE TEAM IN BUFFALO

To establish a program for deep brain stimulation surgery in Buffalo required a cooperative effort between the hospital, the Department of Neurosurgery and initially the Department of Neurology, although later all of it was brought under the umbrella of the Department of Neurosurgery. We determined that there were four essential roles that needed to be played. First was a neurosurgeon who was comfortable with stereotactic neurosurgery. Next was a fellowship-trained movement disorder neurologist. Dr. Kimberly Trinidad was interested in establishing such a program. She cares for the most difficult Parkinsonian patients and certainly the patients who have reached the point where consideration of surgery makes sense. Next was the need for an experienced electrophysiologist and we were fortunate that within Buffalo General Hospital Dr. Richard Stockton, PhD was engaged in the work of intraoperative monitoring. Dr. Stockton brings 25 years of experience with electrophysiology, including a long tenure in the Department of Ophthalmology doing experimental studies and a great deal of experience with single cell recording using microelectrode recording techniques. Finally it was clear that for this program to be successful it would require a significant nursing input. We were able to recruit an experienced Neurology/Neurosurgery nurse, Patricia Weigel. Her duties were to include patient education, patient assessment including pre-operative filming and testing, intraoperative work with the patients and on the surgical side as needed, as well as the key role of programming the deep brain stimulators after their implantation.

Once this team was assembled, we approached the hospital and were able to convince them to buy the appropriate equipment, which consisted of a Radionics CRW-FN stereotactic frame for functional neurosurgery and a Radionics computer workstation to allow planning using MRI and CT scans, including fusion of MRI and CT images. The electrophysiology setup was partially provided by Dr. Stockton but had to be supplemented with some newer equipment purchased by the hospital. Over the course of approximately 1-1/2 years, we were able to accumulate all of their required equipment. There were certainly pitfalls along the way as we discovered that MRI imaging would not be adequate in that we found significant distortion in taking MRI images in the CRW-FN frame. Due to the distortions, we ended up using MRI out of the frame, fused onto CT scans within the frame as the imaging modality. This has proven to be extremely successful. In addition, we recruited the help of Dr. Ronald Alberico, a neuroradiologist from Roswell Park Cancer Institute.

The training for this group of professionals included site visits to at least a dozen different centers where pallidotomy and/or deep brain stimulation was being carried out. The entire team or subsets of the team would travel to the site in question to learn specific parts of the pre-operative assessment, the surgical technique, the post-operative management and the programming. Over the course of about two years, more than 15 visits were made to operating rooms throughout North America. During this time, we were also accumulating our equipment and working with the biomedical engineers at the State University of New York at Buffalo to develop our own guide cannulas and microelectrode drive system. In addition to the operating room site visits, we attended symposia and courses offered through Medtronic Corporation, the company that manufactures the electrodes and the pulse generators. We then began a series of "rehearsals" including electrophysiology using our equipment in laboratory animals and simulations of image fusion with CT and MRI scan of models (melons). We confirmed the accuracy of our imaging techniques and the accuracy of our fusion techniques with actual stereotactic procedures performed on the models. We verified the ability of our microelectrode recording system to successfully record single cells within the brain of laboratory animals. In addition to all of the above activities, we began to evaluate patients who might be appropriate candidates for surgical intervention for either tremor or Parkinson's disease.

PATIENT SELECTION AND EVALUATION

Patients with tremor, which does not respond to medical management, who are medically stable, are candidates for thalamic deep brain stimulation. The tremor must be disabling and interfere with activities of daily living such as eating, dressing and writing. Distal tremor is more easily treated than proximal tremor, but both can be candidates. Head tremor in association with upper extremity tremor can also be treated and there are some reports of isolated head tremor being adequately treated with bilateral VIM thalamic stimulation. Formal neuropsychological testing is obtained in all of these patients to be certain that there is no underlying dementia or cognitive impairment. For patients with multiple sclerosis, it is best if the patient has been free of any MS exacerbations for a period of at least 3-6 months prior to contemplating thalamic electrode placement.

The selection of patients with Parkinson's disease for bilateral subthalamic nucleus stimulation can be very challenging. There are three basic groups of patients who seem to benefit the most. The first are those patients who develop progressive motor fluctuations with severe dyskinesia during their on time and ever lengthening periods of off time. These patients clearly still respond to the Parkinsonian medications and this is one of the requirements for successful subthalamic nucleus stimulation; responsiveness to Dopaminergic agents. The second group is those patients who do not have severe motor fluctuations in the sense of alternating between off and dyskinesia but rather those patients who are spending progressively more of their time in the off state and spending far less of their time in a productive on state. Again, it must be clearly stated that these patients still need to be responsive to Dopaminergic agents but that the response is fading. The third group, which seems to be emerging from the literature, are those patients who have some degree of motor fluctuations, some worsening of off time and are particularly bothered by gait difficulties. Bilateral subthalamic nucleus stimulation can be extremely valuable in helping these patients to regain a more normal ambulation pattern.

The pre-operative evaluation of all Parkinsonian patients prior to bilateral STN surgery includes neuropsychological testing to rule out dementia and extensive medical workup to be certain that the patients have adequate cardiorespiratory reserves to undergo the stressful period of the multiple surgical procedures. They must have excellent blood pressure control, no outstanding coagulopathy or other medical issues; no significant psychiatric issues other than treated depression. Our protocol, besides the above-mentioned testing, does include pre-operative videotaping of each patient in both the on and the off phase of their medication. This also allows us the chance to evaluate the patient when they are off medication (as they will be during surgery for electrode placement). Finally, it is very important that the patient have adequate social support, usually a family member or a caregiver who can help the patient get through this rigorous protocol and assist during the post-operative phase when programming and medical adjustments require a great many visits to the physician's office.

SURGICAL TECHNIQUE

We have chosen to use both MRI and CT scans for image guidance for our stereotactic procedures. During our testing, prior to initiating patient work, we determined that MRI imaging in our hands, using the CRW-FN frame, had too much distortion and would not be adequate as the sole imaging modality. We therefore obtain an MRI scan pre-operatively with the patient not in the stereotactic frame. This MRI is obtained in the orientation of the AC-PC plane. In addition, we take a second set of images, coronal to the AC-PC plane. Prior to the day of electrode placement the neuroradiologist and the neurosurgeon go over these images, establish the measurements related to anterior and posterior commissures and determine where the target point would be based on MRI alone. The advantage of this is that we are able to visualize the red nucleus very easily and the subthalamic nucleus is located just anterior and lateral to the red nucleus. In fact, on some of the better quality scans, we are able to visualize what we believe is the subthalamic nucleus. For stereotactic purposes, the distortion inherent in MRI makes it less than ideal as the single modality. The distortion must be tested for with <u>any</u> frame and any MRI scanner.

The day of surgery to place the first electrode, the patient has placement of the stereotactic frame using only local anesthesia with no sedation. The

CT scan is then obtained and by gently angling the patient's head we achieve the correct position to allow 3mm slices to be obtained; again exactly in the AC-PC plane. The pre-operative MRI and the CT scan in the frame are now fused using a computer workstation, which was purchased from Radionics Corporation. The image fusion preserves the accuracy of the CT scan but allows us the enhanced visualization of the MRI scan. We use this for target planning and also we are able to project the trajectory onto axial, coronal and sagittal images, which allows us to choose a gyral entry point, to avoid sulci, and to avoid the ventricles. For the subthalamic nucleus (STN) our starting target is 3mm behind the mid commissural point, 12mm lateral and 4mm deep to the AC-PC plane. The frame is generally placed at about 7:00a.m. and we are ready to enter the operating room between 9-9:30a.m. While the computer planning is going on, the patient is taken to the pre-operative holding area where an intravenous line is started and a Foley catheter is placed. The patient is interviewed and evaluated by the anesthesiologist at this time, although no sedation is used until after the electrode is secured.

The patient is now brought into the operating room. They are positioned on the operating table in a semi-seated position and secured to the table with a convertor from the Mayfield system to the CRW frame. This allows very nice rigid fixation, but with the semi-seated position the patient is relatively comfortable and the body is accessible for examination by the neurologist intraoperatively, as well as visualization of the face and extraocular movements. The incision is linear parasagittal, approximately 3.5cm off the midline. The bur hole is placed at or near the coronal suture. This is all done under local anesthesia without sedation. The stereotactic target chosen on the computer workstation is now programmed on the CRW base ring and phantom and then the guide cannula is stereotactically placed at a point 10mm above the subthalamic nucleus target. We have chosen a lateral entry point to avoid the lateral ventricle and to progress through white matter (i.e., the corticospinal tract) enter the thalamus and then through the thalamus into the zona incerta, the subthalamic nucleus, and deep to that the substantia nigra. With the guide cannula in place, the introducer is removed and the microelectrode is now inserted. The microelectrodes are purchased from World Precision Instruments in Sarasota, Florida. They are Tungsten microelectrodes 12" long, .5 ohm resistance. We begin the microelectrode recording track 1mm distal to the guide cannula and proceed for 10-12mm until we believe we have entered the substantia nigra. Whenever we isolate a single cell and record from it, we examine the patient to include joint movement of upper extremity, lower extremity and face, tactile sensation of face, upper and lower extremity. We are trying to correlate kinesthetic cells with the cells being recorded in the subthalamic nucleus and trying to correlate the topography within that nucleus. The transition in the substantia nigra is marked by a change in the frequency. When we believe that we have reached the substantia nigra, we then change over the circuitry so that we can carry out microstimulation. Microstimulation is carried out using a train of electrical pulses: train duration 0.8 seconds, rate 300/s, constant current at 10-100 microamps with a pulse duration of 0.2 seconds. Microstimulation is valuable both for positive effects, reduced tone or increased speed of movement, and negative effects such as paresthesia, diplopia, or motor contractions. We stimulate at 1mm increments beginning in substantia nigra as we withdraw the microelectrode. Microstimulation has proven to be a very nice adjunct to the microrecording technique.

At the conclusion of the microrecording and microstimulation phases, we review the pattern of cell, which we encountered, and the side effects, which were encountered during stimulation, and try to determine where we are in the brain. If all of the data favors that we actually made a good trajectory through the subthalamic nucleus and that the depth of subthalamic nucleus that we traversed was more than 4mm then we are satisfied that we have a good place for inserting the macroelectrode. In some instances, we find that we did not get adequate recording, that the microstimulation did not give a positive benefit, or that the microstimulation gave us side effects. The entire pattern is reviewed. If we believe we are, for example too far anterior, too far lateral, or too far medial, we then would contemplate making a second microelectrode recording. It has been our experience that if we are going to make a second recording we would make the movement of a full 1.5 to 2mm in that trying to make lesser moves we do not think actually would give us a second separate track. We think it would blend with the first track. To make a second microelectrode re-

cording track the microelectrode is removed, the stylet is introduced back into the guide cannula, the guide cannula is removed, the frame is then reset to the new coordinates and then the guide cannula is reinserted. Every time we insert the guide cannula we seal the bur hole site with Fibrin glue, tissue sealant, to prevent CSF leak, which we think could lead to brain sag during the procedure. In our experience thus far, we have required more than one microelectrode in about 1/3 of the cases. When we are satisfied with the microelectrode and microstimulation and believe that we are in the correct location, the microelectrode is removed and through the guide cannula the macroelectrode is inserted to the appropriate depth. The system is such that the macroelectrode passes through the guide cannula without any difficulty with its stylet in place. We now proceed to testing of the clinical response through the macroelectrode. A variety of combinations using the positive and negative (anode and cathode) are carried out until we determine the pattern of response for this electrode placement. Again, we are looking for both positive effects with a reduction in tone and increase in speed of movement and for any side effects, which would help us to determine that we were not in the correct orientation. Very often, the physical act of inserting the macroelectrode will lead to a change in the patient's tone, which we term a microsubthalamotomy effect. This will last the remainder of the testing phase. Indeed it can last for up to several weeks after insertion of the electrode. This also helps us to be certain that we are in the right position. Once the testing with the macroelectrode has been carried out and we have satisfied ourselves of its correct positioning, it is time to secure the electrode to the bur hole site at the bone edge.

To secure the electrode, there are several commercial systems available. What we have ended up using is a simple bur hole cover made out of titanium with titanium screws. We use a C-arm fluoroscope in the operating room to mark the distal progression of the electrode. As we are removing the stylet and removing the guide cannula, we continuously monitor under fluoroscopy to be certain that the electrode does not migrate. Once the stylet is out and the guide cannula has been backed out over the electrode, we now put the bur hole cap in place and this gently compresses the electrode to the bone edge. A second small microplate is used about 1cm distally again to secure this down so there are two points of fixation on the electrode thus preventing any migration. We tunnel the distal tip of the electrode to the parietal boss and leave it buried underneath the scalp at that point so that when we come back later to place the pulse generators it will be accessible without having to reopen the bur hole site. The wound is then copiously irrigated and closed. The patient is removed from the frame and typically kept in the hospital for 24 hours, during which time careful blood pressure monitoring and control is carried out. In addition, we perform either a CT or an MRI scan the morning after surgery to be certain there is no bleeding and also to check electrode positioning. The patients are discharged home 24 hours after electrode placement. Typically, the second electrode is placed approximately two weeks later. The surgery to place the second electrode is done in exactly the same fashion as outlined above. However, we do not need MRI images for the second electrode because if the first electrode was successful we use the CT alone and create a mirror target point to the first electrode placement. Each electrode typically takes 6-8 hours from frame application until the patient arrives in the recovery room.

Approximately two weeks after the second electrode is placed and the patient has recovered from that operation, the patient is brought in for the third surgical procedure; this is done under general anesthesia. This is to place the pulse generators to drive the deep brain stimulating electrodes. The pulse generators are placed in the same position as a cardiac pacemaker, that is just below the clavicle lateral to the midline. There is also a need to tunnel from the parietal boss to this infraclavicular site and bring a connecting wire through that. Under general anesthesia, we do one side and then we turn the patient the opposite way, re-prep, re-drape and do the second side. Other centers have chosen to configure the surgeries differently. Some people put both electrodes the same day and some people put the pulse generators the day of the second electrode. There are a variety of configurations that are possible. Once all of the hardware is in position and the microsubthalamotomy effects have worn off, then the patient is ready for programming.

The first session for programming the deep brain electrodes is done with the patient off all medications from the night before. The patient therefore arrives in the office in the off state clinically and

each DBS electrode is tested individually to determine the best contact points to relieve the maximum number of symptoms (each electrode has four contact points, thus allowing many different anode, cathode combinations). We certainly do see differing effects of differing electrode combinations in terms of rigidity, tone, bradykinesia and gait. We are trying to alleviate as many of the symptoms as possible and optimize the patient's function. Typically, the first programming session will be about 3-4 hours of testing each side individually without medication. Then, when the best parameters have been selected, the stimulators are both turned on and the patient is given a dose of their anti-Parkinsonian medications. About an hour later, when the medications have become effective, we then get our first glimpse of the combination of medication plus stimulation. At this time, adjustments in stimulation may have to be made and depending on the patient's response, there may need to be a decrease in the anti-Parkinsonian medications. Over the next six weeks, the patients are typically seen every 1-2 weeks for further adjustments in both programming the stimulators and in adjusting the medications. During this time, the neurologist and the nurse clinician are in frequent contact with the patient and a tremendous amount of patient education is required before they are comfortable using their stimulators. Most patients find that they leave the units on 24 hours a day. After this initial programming period of 4-6 weeks, most patients reach a relative plateau with a lower dose of medicine and improved level of function. What has been reported in the literature and what we are seeing ourselves is that the off time is markedly diminished with the deep brain stimulating system. In addition, there has been a significant reduction in dyskinesias for the patients who are dyskinetic. This may be related directly to stimulation or may be related to the fact that most patients are able to decrease the dosage of Parkinsonian medications. We are not seeing a marked enhancement of their best on time but rather just longer periods spent at their best on time.

There are two basic types of complications; those associated with surgery and those associated with stimulation itself. The surgical complication rate in our hands mirrors that of the existing literature. Hemorrhage at the time of electrode insertion should be in the range of 2-5%. Infection of the system should be in the 5% range. Electrode breakage or erosion through the skin is seen in as many as 15% of patients. There have been some improvements in the hardware, which may bring that number down, but that has been the highest surgical complication problem, fractures and scalp erosions. Complications of stimulation can include depression, which has been reported, cognitive impairment, which has been reported, and a very unusual phenomenon called eyelid-opening apraxia[13,14]. We have seen this. In this situation, patients have a great deal of trouble opening their eyes and it is an apraxic phenomenon and does go away when stimulation parameters are changed. The issue becomes optimization of symptom reduction may leave you with the side effect of the eyelid-opening apraxia, and then it is for the patient to choose if they can live with that to get the benefit of the stimulator. Many patients have mild paresthesias at times with stimulation, but these are usually tolerable. The batteries to drive the systems typically will last a number of years and surgery to replace the batteries can be done with local anesthesia and sedation. Despite this being a very rigorous surgical endeavor for the patients, the benefit has been quite worth the effort. In our series, 2/3 of the patients would report a very significant benefit while 1/3 have had minor benefit from the deep brain stimulation system for Parkinson's. Overall, we have seen a reduction in the need for Parkinsonian medications and a dramatic decrease in the incidence of dyskinesias in the patients who had them pre-operatively. Gait has improved in almost all of the patients.

Deep brain stimulation is technically challenging but offers a significant potential to improve the quality of life for patients with Parkinson's disease or disabling tremor[15,16,17].

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