In the past few years, DBS with chronically implanted electrodes and IPGs has become an accepted treatment option for medically refractory movement disorders. Current targets include the VIM for patients with tremor, the globus pallidus internus for dystonia, and the globus pallidus internus and the STN for PD. Many patients considered candidates for DBS are elderly, particularly those with PD, and therefore the chance that these patients may also have cardiac disease is increased. Thus far, DBS has been considered to be contraindicated in patients with cardiac pacemakers. Because cardiac pacemakers and the pulse generators used for DBS are both susceptible to external electromagnetic fields, it has been thought that the risk of possible interference between the two systems would not justify their concomitant use. Electrical activity from other sources, including skeletal muscles, electrocautery, and transcutaneous electrical nerve stimulation, may inhibit demand pacemakers. Although the DBS system might impair the ability of the cardiac pacemaker to sense heart activity and subsequently to prevent the pacemaker from pacing the heart, it has also been feared that the cardiac pacemaker could affect the performance of the DBS system. There have been few reports on the simultaneous use of DBS systems and cardiac defibrillators in single patients, but even fewer data are available on the true risk of the concurrent use of DBS systems and cardiac pacemakers. In this paper we report our experience on the safe use of long-term DBS in six elderly patients with movement disorders who had cardiac pacemakers.

Clinical Material and Methods

Six patients with cardiac disease were referred to our department to evaluate whether long-term DBS was indicated for treatment of their movement disorders. Five of these patients had previously received a cardiac pacemaker for various cardiac disorders (Table 1). In one patient (Case 3), a cardiac pacemaker was implanted after he had received a...
unilateral DBS system; thereafter, he received an additional DBS device for the other side (see Illustrative Cases). Four patients suffered from advanced PD and two patients had ET. There were four men and two women in the study with a mean age at surgery of 69.5 years (range 63–79 years). All patients underwent extensive clinical and cardiac examinations to allow the safe use of DBS for the treatment of their movement disorders. Surgery to implant the DBS device was generally performed using local anesthesia with principles and techniques described elsewhere. Target settings included routine ECG and Holter ECG studies.

The preliminary coordinates, based on the line connecting the anterior and posterior commissures, were the following: for the VIM, \( x = 11 \) to 12, \( y = -1 \) to 2, and \( z = 0 \); and for the STN, \( x = 11 \) to 12, \( y = -2 \) to 3, and \( z = -4 \). The electrodes and IPGs used for DBS were manufactured by Medtronic, Inc. (Minneapolis, MN). Surgery to implant the DBS system was assisted by intraoperative cardiac monitoring.

When the pacemakers were programmed, great care was taken to minimize any interference between the two systems. Postoperatively, extensive tests of the programming of the DBS settings included routine ECG and Holter ECG studies.

**Results**

No adverse events occurred during surgery. Four patients underwent VIM stimulation, which was unilateral in three and bilateral in one. Two patients underwent STN stimulation. Generally, the IPGs were implanted on the side contralateral to the cardiac pacemaker. In one of the patients with bilateral DBS, a dual-channel IPG (Kinetro) was used. All patients benefited from the procedure. In all cases, bipolar sensing was chosen for the cardiac pacemakers. The quadripolar DBS electrodes were programmed for bipolar stimulation. For patients undergoing DBS in the VIM, contacts 0 and 2 were generally chosen for long-term stimulation, whereas for patients undergoing STN DBS the two uppermost contacts were used. In one patient bipolar DBS was later changed to unipolar without causing interference with the cardiac pacemaker, which was in bipolar sensing mode. Several control ECG studies, including 24-hour monitoring, did not demonstrate any interference between the two pacemakers in any patient. At the time this paper was written the patients had been followed up for a mean of 25.3 months (range 4–48 months).

Table 1 shows the pulse generators and configurations used for cardiac pacing and DBS. Clinical management in the individual patients is detailed in the following case summaries.

**Illustrative Cases**

**Case 1**

This 64-year-old woman was referred for functional stereotactic surgery to treat a disabling tremor. She had a 10-year history of familial ET, which could not be satisfactorily controlled by medical treatment. During the neurological examination she displayed severe postural and kinetic tremors in both of her arms. In addition there was continuous shaking of her head as soon as she assumed an upright position. She was markedly restricted in her daily activities including housework, drinking, and eating. Computerized tomography studies of her brain yielded unremarkable findings.

Three years earlier a cardiac pacemaker (Synchrony III; Pacesetter, which is now St. Jude Medical, Inc., St. Paul, MN) had been implanted for the treatment of syncopal attacks due to third-degree AV block. The pacemaker had bipolar leads in both chambers and the atria, and was configured in the DDD mode with bipolar sensing and pacing. After implantation of the cardiac pacemaker the patient ceased to have any further syncopal attacks.

Because the patient’s tremor was more pronounced on her right side and she was right handed, it was decided to perform a unilateral ablative thalamic procedure. The tremor was completely abated after the patient underwent a left-sided VIM thalamotomy. One year postoperatively, the right-sided tremor was still absent; however, the left-sided tremor had become worse. Because of the increased risks associated with bilateral ablative thalamic surgery, the option of DBS on the side contralateral to the previous thalamotomy was considered. Preoperatively, the configuration...
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Fig. 1. Case 1. Chest x-ray film obtained after the implantation of a cardiac pacemaker (on the right side) and an impulse generator (on the left side), which is connected to a quadripolar electrode in the left VIM to treat ET.

of the cardiac pacemaker was checked and optimized. The parameters of the pacemaker were set as follows: configuration DDD, atrial and ventricular electrodes with bipolar sensing and stimulation, sensitivity 2 mV, rate 60/minute, and refractory time 250 msec.

During stereotactic implantation of the quadripolar DBS electrode, cardiac function was monitored continuously to minimize the risk of any interference of the DBS system with the cardiac pacemaker. Following induction of general anesthesia, the IPG (Itrel II) was implanted into a subcutaneous pouch below the left clavicle directly after the head frame had been removed (Fig. 1).

After step-wise programming and adjustment of the DBS settings the left-sided tremor and head tremor were fully controlled. At the last follow-up examination, which was performed 4 years postoperatively, the DBS parameters were as follows: bipolar stimulation, amplitude 2.6 V, frequency 145 Hz, and pulse width 210 μsec. Several control ECG studies, including 24-hour monitoring, did not reveal any interference between the two systems.

Case 2

This 69-year-old man was referred for surgical treatment of parkinsonian tremor. He had a 12-year history of PD. Several drugs had failed to control his disabling tremor. During the neurological examination the patient displayed marked tremor at rest, which was more pronounced on the left side, but only minimal bradykinesia and rigidity. Imaging studies of his brain were unremarkable. Given his almost monosymptomatic tremor, he was thought to be an excellent candidate for thalamic surgery.

Seven years earlier a cardiac pacemaker had been implanted for refractory bradycardia (Biotronik Dromos; Biotronik GmbH, Berlin, Germany). The cardiac pacemaker was configured in the DDD mode with bipolar leads placed in both chambers and atria, unipolar pacing, and bipolar sensing. Appropriate function of the cardiac pacemaker was confirmed by ECG monitoring.

A quadripolar DBS electrode was implanted into the left VIM. During physiological definition of the target, continuous ECG monitoring was performed. The tremor was suppressed completely during test stimulation via the externalized electrode. The test stimulation did not interfere with the function of the cardiac pacemaker according to ECG tracings. Therefore, following induction of general anesthesia an IPG (Itrel II) was placed in a subcutaneous pouch below the right clavicle.

Postoperatively, extensive testing performed during programming of the DBS settings included routine ECG and Holter ECG studies. Unipolar DBS was shown to affect the traces, which made them difficult to interpret. Figures 2 and 3 demonstrate how unipolar DBS can interfere with surface ECG and intracardial ECG signals. Because of the interference after the initial trials bipolar atrial sensing of the cardiac pacemaker and bipolar DBS programming were chosen for continuous stimulation. Using these settings, there was no disturbance in the function of the DBS device or the cardiac pacemaker.

At the last follow-up examination, the parameters for the pacemaker and the DBS device were as follows: for the cardiac pacemaker, DDD configuration, atrial and ventricular electrodes with bipolar sensing and stimulation, sensitivity 5 mV, rate 55 to 130/minute, and refractory time 300 msec; for the DBS device, bipolar stimulation, amplitude 2.5 V, frequency 130 Hz, and pulse width 120 μsec. Follow-up data obtained for 3 years postoperatively were unremarkable.

Case 3

This 74-year-old man with a 50-year history of tremor was referred for surgical management after medical therapy had failed to alleviate his symptoms. His tremor was classified as ET. He was unable to tolerate medication because of the side effects. His neurological examination revealed pronounced bilateral tremor especially during active motion. His tremor precluded all social functions and dramatically interfered with activities of daily living. A magnetic resonance image of his brain was unremarkable. This patient was believed to be a suitable candidate for bilateral thalamic DBS. He had a history of angina and had undergone successful angioplasties performed 2 to 6 years prior to this ad-
mission. His cardiologist concurred that he was a candidate for thalamic surgery.

A quadripolar DBS electrode was inserted into the left VIM. The tremor was suppressed completely during intraoperative testing. Following induction of general anesthesia, an IPG (Trel II) was placed in a subcutaneous pouch below the left clavicle. The remainder of the operation and recovery period were unremarkable. Because of the patient’s overall health and at the recommendation of his cardiologist, only one DBS system was implanted at this operation.

Three months later, the patient was scheduled for implantation of a contralateral DBS electrode. The procedure was aborted because he suffered an episode of severe bradycardia and the wound was closed. A cardiology consultation was obtained in the recovery room. The bradycardia could not be managed medically. The patient was diagnosed with sinoatrial node dysfunction and he underwent placement of a pacemaker (Prodigy, model 7860B; Medtronic, Inc.). Settings for the pacemaker included a sensing threshold of 10.2 mV for the ventricle and 5.4 mV for the atrium, rate of 90 to 110/minute, and a refractory time of 350 msec. Recovery from the aborted DBS surgery and implantation of the pacemaker was uneventful. Appropriate function of the cardiac pacemaker was confirmed by numerous ECG studies. Both the DBS system and the cardiac pacemaker were functioning optimally. Finally, the patient’s condition was diagnosed as sick sinus syndrome.

One month later, a quadripolar DBS electrode was implanted into the right VIM. Continuous ECG monitoring was performed. A test stimulation showed no interference with the cardiac pacemaker according to ECG monitoring. The tremor was dramatically reduced during test stimulation intraoperatively and an IPG (Soletra) was implanted at the same setting in a subcutaneous pouch below the left costal margin. The operation was entirely uneventful from both a neurological and cardiological standpoint.

Postoperative programming of the bilateral DBS systems was unremarkable. The configuration at the last follow-up examination was the following: 1) right side, bipolar stimulation, amplitude 3.1 V, frequency 135 Hz, and pulse width 120 μsec; and 2) left side, bipolar stimulation, 2.9 V, 160 Hz, and 210 μsec. No obvious abnormalities in function were noted in either the pulse generators implanted for the two DBS systems or the cardiac pacemaker based on extensive electrical monitoring. Follow-up examinations conducted for 4 years postoperatively yielded unremarkable findings.

**Case 4**

This 63-year-old man was referred for surgical treatment of PD, which had been diagnosed 16 years earlier. He had exhausted medical measures to treat his disease and had undergone a left-sided pallidotomy at another institution 6 years previously. During that procedure he sustained a basal ganglia hemorrhage that resulted in a right hemiparesis. His primary complaint consisted of bradykinesia and rigidity and he also had levodopa-induced dyskinesias. Medical management with levodopa and dopaminergic agonists only partially controlled his symptoms. A computerized tomography scan of his brain revealed a defect in the left basal ganglia including the internal capsule, which was due to the hemorrhage. The patient was scheduled for STN DBS.

Nine months prior to referral, he had undergone a revision of his cardiac pacemaker, which had originally been placed for an AV block. The pacemaker was a Sigma 200 SR (model no. SS R203B; Medtronic, Inc.), which was configured in demand mode with leads placed in both chambers. Optimal function of the cardiac pacemaker was verified by ECG. The ventricular capture rate was 81/minute, the sensitivity 2.8 mV, and the refractory time 330 msec.

A quadripolar DBS electrode was implanted into the right STN. Continuous ECG monitoring was performed. Test stimulation using the screener did not interfere with any function of the cardiac pacemaker according to the ECG monitoring. During the same operation the IPG (Soletra) was implanted into a subcutaneous pouch below the left clavicle. The operation was uneventful.

Postoperative programming and monitoring of the IPG and the cardiac pacemaker revealed no interference between the two systems. The settings of the IPG at the last follow-up examination were the following: bipolar stimulation, 3.5 V, 135 Hz, and 90 μsec. Follow-up data obtained for 1 year postoperatively were unremarkable.

**Case 5**

This 68-year-old woman was referred for surgical treatment of PD, which she had had for 12 years. Her primary complaint and feature of the disease was tremor. Medical management caused serious side effects. Her neurological examination revealed pronounced tremor at rest primarily on the right side. Only minimal bradykinesia and rigidity were present. Again this patient was believed to be a suitable candidate for thalamic DBS.

Two years earlier she had received a cardiac pacemaker for refractory supraventricular tachycardia (Wolf-Parkinson-White) after ineffective electrical ablation. The device was a Thera 1 DR (model no. 7960IB; Medtronic, Inc.) pacemaker, which was configured in the demand mode with leads in both chambers (DDD). Sensitivity adjustments...
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were set at 0.5 mV for the atrium and 2.8 mV for the ventricle. The rate was 60 to 120/minute, and the refractory time was set to 230 msec.

A quadripolar DBS electrode was implanted into the right VIM. Continuous ECG monitoring was performed. The tremor was completely abolished during test stimulation, which did not interfere with any function of the cardiac pacemaker according to ECG monitoring. During the same operation following induction of general anesthesia, the IPG (Soletra) was implanted within a subcutaneous pouch below the left clavicle. The operation was entirely uneventful.

Postoperative programming of the DBS device was also uneventful. In this case, unipolar DBS was clearly more effective than bipolar stimulation. Therefore, it was decided to continue with unilateral stimulation in this case. The parameters for the IPG at the last follow-up examination were the following: unipolar stimulation; amplitude 2.4 V, frequency 130 Hz, and pulse width 210 μsec. No obvious abnormalities in function were noted in the pulse generator for either the DBS or the pacemaker. Follow-up data obtained at 4 months postoperatively were unremarkable.

Case 6

This 79-year-old man was referred for treatment of tremor. He had a 5-year history of PD with predominant tremor at rest and a gait disturbance. His symptoms were not satisfactorily controlled by levodopa and dopaminergic agonists. The tremor interfered markedly with his daily living activities, in particular with drinking and eating. The neurological examination revealed gait ignition failure and hypomimia as well as postural instability and mild rigidity. He was scheduled for bilateral STN DBS.

A cardiac pacemaker (Affinity DR, model 5330; St. Jude Medical) had been implanted 2 years earlier for treatment of bradyarrhythmia due to a first-degree AV block. The cardiac pacemaker was configured in the DDD mode with bipolar sensing and electrodes placed in the atrium and chamber, and bipolar stimulation in the atrium and unipolar stimulation in the chamber.

Before stereotactic surgery, the cardiac pacemaker was reconfigured. Both electrodes in the atrium and chamber were programmed in the bipolar mode for sensing and stimulation, with the following configuration: sensitivity 4 mV, rate 60 to 110/minute, and refractory time (chamber) 250 msec.

Quadripolar electrodes were implanted bilaterally in the STN. Intraoperative ECG monitoring showed no interference with the cardiac pacemaker during test stimulation. The electrodes were externalized to measure field potentials for a few days. After this time, an IPG (Kinetra) was placed within a left-sided subcutaneous pouch following induction of general anesthesia.

Postoperative screening of the cardiac pacemaker showed no interference between the two systems. Figure 4 shows the surface and intracardiac ECG printouts. The configuration of the DBS at the last follow-up examination was the following: bipolar stimulation; amplitude, left side 2.8 V and right side 3 V, frequency 130 Hz, and pulse width 60 μsec. Follow-up data obtained for 4 months postoperatively were unremarkable.

Discussion

The present study shows that DBS for treatment of movement disorders in elderly patients with cardiac pacemakers is feasible and reasonably safe, provided certain precautions are taken to avoid interference between the two systems. Our results concur with experience gathered earlier in patients with cardiac pacemakers who have undergone long-term SCS for treatment of refractory pain or vascular disease. Apart from technical considerations, as outlined later in this section, a careful selection of patients and their ability and willingness to cooperate in thorough neurological and cardiological follow-up monitoring are absolute prerequisites.

Given the changing age distribution in the general population in Western countries, the widespread use of cardiac pacemakers nowadays, and the ever-increasing expansion of indications for DBS, the question of whether a patient should be supplied with both a cardiac pacemaker and a DBS system will arise more frequently in the near future. The frequency of the use of cardiac pacemakers varies somewhat from country to country, but there is a clear tendency that such systems are being used more often today than two decades ago. In Germany, for example, there were 127,000 patients living with cardiac pacemakers in 1982. In contrast, in 2001, this number had increased to more than 200,000 according to the central registry for pacemakers in Germany. Fewer than 20% of these patients were younger than 65 years. Similar to DBS, new technical developments have contributed markedly to the more widespread use and broader indications for cardiac pacemakers.

The question of whether cardiac pacemakers interfere with other pulse generators also has been a topic associated with SCS. Spinal cord stimulation is now an established treatment for neuropathic pain and vascular disease including angina pectoris. In particular, patients with cardiac and vascular diseases may also require cardiac pacemakers. Safe management with simultaneous stimulation has been described in several case reports. Romano and colleagues reported on a series of 10 patients with a mean age of 73 years in whom both a cardiac pacemaker and an SCS...
device had been implanted.\textsuperscript{23} No interference between the two systems was found in nine of the 10 patients after implantation or during follow-up review. In one patient who had a unipolar configuration of cardiac pacemaker, however, intermittent inhibition of the pacemaker was noted when the stimulation amplitude of the SCS was increased. Interference was also found to be dependent on the frequency that was used. Although the experience with cardiac pacemakers gleaned from treating patients with SCS is not immediately transferable to DBS, the main lesson to be learned is that the configuration of the cardiac pacemaker should be bipolar for sensing and, preferably, also for pacing.

There are only limited data on the simultaneous use of cardiac pacemakers and DBS systems. The successful co-implantation of cardioverter–defibrillator systems and pulse generators for DBS has been reported in three previous patients who underwent thalamic or STN stimulation for treatment of refractory tremor and PD.\textsuperscript{21,25,28} The neurostimulation systems did not affect the performance of the cardiac pacemakers when bipolar sensing was used. Cardioverter–defibrillator shock, however, caused a resetting of the IPG when bipolar sensing was selected.\textsuperscript{57} In another patient with a radiofrequency-coupled system and an external pulse generator for long-term thalamic stimulation, external cardioversion led to a thalamotomy.\textsuperscript{29} Long-term DBS with the concurrent use of other cardiac pacemaker systems has only been reported in a single abstract.\textsuperscript{58}

Cardiac demand pacemakers are designed to inhibit their output when electric signals from spontaneous cardiac activity are detected. Cardiac pacemakers can be programmed in different configurations. The configuration depends on where the sensing takes place (A = atrium, V = ventricle, or D = both), where the pacing is directed (A = atrium, V = ventricle, or D = both), and in which way the stimulation interferes with the heart rhythm (I = inhibition, T = trigger, or D = both). The configuration that is chosen, of course, is determined by the underlying cardiac disorder. The majority of cardiac pacemakers used nowadays are programmed in the DDD or VVI mode. Furthermore, cardiac pacemaker electrodes can be programmed either in the unipolar or bipolar mode. Today almost all pacemakers are programmable and the most frequently used configuration is bipolar sensing.

When considering DBS in a patient with a cardiac pacemaker, it is absolutely mandatory to know whether the programming can be switched from unipolar to bipolar stimulation. Older models worked exclusively in the unipolar mode. In 1982, for example, 36% of cardiac pacemakers implanted in Germany were not programmable and 47% were multiprogrammable.\textsuperscript{5} In subsequent years, however, more and more multiprogrammable pacemakers were selected, accounting for 97% of those implanted in Germany in 1992. In 1985, ventricular leads were unipolar in 96.9% of patients and bipolar in only 3.1%. In 1998, however, 57.4% of the implanted leads were unipolar and 42.6% bipolar.\textsuperscript{8} This switch to the more frequent use of the bipolar electrode configuration is also shown by newer data from 2001.\textsuperscript{19}

As shown, unipolar configuration of DBS can interfere with the interpretation of surface and intracardiac ECG signals. Such disturbances are variable, however, and are dependent on the filter settings of the ECG machinery (for example, the availability of notch filters for different frequencies). According to our suggestions, if the bipolar sensing mode of the cardiac pacemaker and the bipolar configuration of the DBS is used, no artifacts will appear on the ECG traces.

Although the chance of interference between a cardiac pacemaker and a DBS system theoretically is low, given the different range of frequencies used—cardiac pacemakers being susceptible to lower frequencies and DBS devices usually set at 130 Hz or greater—several other measures should be taken to minimize this risk further. First, pulse generators of both systems should not be implanted in the same side. For this purpose, it may be necessary to implant the IPG of the DBS system contralateral to the quadripolar electrode. The risk of any interference is lowest, in general, when both systems are programmed in bipolar configurations. Absence of interference then is attributed to the small electrical field of stimulation, on one hand, and the small sensing circuit, on the other hand. It is unclear, however, whether the same is true when higher voltages are used. In single instances in which bipolar DBS will not be as effective as unipolar DBS, the latter may be chosen as an alternative. This also appears to be safe as long as the cardiac pacemaker is programmed in the bipolar sensing mode.

Conclusions

Long-term DBS for treatment of movement disorders can be performed in patients with cardiac pacemakers under certain conditions. The fundamental criteria for safe management is the use of the bipolar configuration for both devices and the strict adherence to follow up on the patient’s clinical status and the devices’ settings. If it is necessary for the patient to achieve a better outcome, the DBS system may be programmed in the unipolar mode, but the cardiac pacemaker should be set for bipolar sensing. Postoperative ECG studies are mandatory whenever settings of the DBS device are changed.

References

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Received March 14, 2004. Accepted in final form July 30, 2004.
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